
SCOPE NEWSLETTER

NUMBER 89

November 2012

IWA NRR conference summary

Harbin China, September 2012

Nutrient Removal and Recovery Conference

The IWA (International Water Association) NRR Conferences bring together worldwide the water industry and R&D, engineering and process experts in P and N removal and recycling. **Key trends, challenges and new solutions in sewage nutrient removal presented at the 2012 NRR Conference (Harbin, 23-25 Sept. 2012)** included developments in biological nutrient removal (eg. Anammox), reuse of water and energy and nutrient recycling.

P recycling processes

Potato industry wastestreams

Pilot and full scale struvite recovery

Results of three pilot and one full scale plant treating potato processing and dairy wastewaters showed successful recovery of phosphate as struvite pellets, subject calcium concentrations or ratios in treated water.

Composting

Struvite and NOx emissions

Struvite precipitation reduced nitrogenous emission from swine manure composting by over 50%.

Dairy manure

Using magnesium to precipitate calcium phosphate

Laboratory scale fluidised bed reactors were tested to precipitate calcium phosphate, by pH increase and magnesium sulphate dosing, from flushed dairy manure after solid-liquid separation.

Crab shells, mussel shells

P-recovery by adsorption to shells

Further laboratory tests show the effectiveness of calcinated mussel shells or uncalcinated crab shells to adsorb phosphates from pure solutions.

P-recovery route assessments

Netherlands

Assessment of options for P-recovery from manures

A range of treatment scenarios for pig manure were assessed, looking at energy recovery, solid-liquid separation, and P-recycling through production of solid manure products, use in phosphate or fertiliser industry, phosphate precipitation processes.

Comparative goal-oriented LCA

Assessment of sewage sludge treatment considering P-recycling routes

Five conventional routes for sewage sludge disposal were compared to SUSAN / ASH DEC type thermal + chlorine donor P-recovery, looking at material and energy flows, LCA and statistical entropy analysis (material dissipation).

Review

Summary of P-recovery routes

Overview of current directions for phosphorus recovery technology developments covering in particular adsorption media, biologically mediated precipitation and improving struvite recovery techniques.

Future events

Brussels, 6-7 March 2013

European Sustainable Phosphorus Conference

<http://www.espc2013.org/>

Monte Carlo, 25-27 March 2013

Phosphate industry conference

<http://www.crugroup.com/events/phosphates/>

Beijing, 18-20 June 2013

Global TraPs world conference

www.globaltraps.ch

Vancouver, 28-31 July 2013

International Nutrient Removal and Recovery 2013: trends in resource recovery and use.

<http://www.wef.org/nutrients/>

Call for abstracts open until 12th December 2012

Harbin China, September 2012

IWA NRR (Nutrient Removal and Recovery) Conference

The IWA Nutrient Removal and Recovery (NRR) Conference brought together some 170 delegates and speakers from 26 countries, in Harbin (China's 10th city, with an urban area population of c. 11 million, and one of China's richest multicultural centres), hosted by the Harbin Institute of Technology, one of the country's top universities in environmental engineering.

From waste to resource

Plenary talks by leading international and Chinese experts underlined the massive water management and sanitation challenges facing today's world, and the **unavoidable need to move from perceiving sewage as "waste" to "resource"**, with recovery of energy (carbon, organic nitrogen) and recycling of water, phosphorus and other nutrients.

Glenn Daigger, IWA (International Water Association www.iwahq.org) opened the conference by summarising the massive challenges facing water management today and tomorrow:

- **Water scarcity**, driven by growing population, water use linked to economic growth, climate change and urbanisation
- **Inequality**: 50% of the world's population do not have safe water and have no access to sanitation, 80% have no sewage treatment
- **Overstepping of planetary boundaries** (the Earth's carrying capacity) for phosphorus and nitrogen
- **Dependence of the economy on water** (for industry and other activities) – businesses are beginning to recognise this risk
- **Urban utilities are mostly not financially sustainable** and lack the resources to address these issues
- **Massive impacts of climate change** on all aspects of the water cycle



These pressures mean that increasingly water will not be simply 'collected', but manufactured, by harvesting urban rainwater, by improving efficiency and by recycling water from wastewaters. **Sewage in general must become a resource for recovering water, energy and nutrients, and no longer a waste.**

In this context, phosphorus recycling will be part of an integrated cycle of water management, including water availability, nutrient dispersal avoidance, nutrient resource stewardship and recycling and energy neutrality at all stages (including water and sewage transport, heat recovery ...).

James Barnard, Water and Environment Federation Fellow, confirmed these pressures on water management. He concluded that biological nutrient removal is a known and reliable technology, provided that it is managed adequately. He considers that **increasing pressure on phosphate resources worldwide will push towards P-recovery and recycling**, and that this benefits in all circumstances from using biological phosphorus removal and avoiding chemical P-stripping (iron dosing).

Murray Moo-Young, University of Waterloo Canada, emphasised the need for scientists, and in particular students, to be ambitious in addressing environmental challenges, and to think and learn broadly (as a complement to specialist knowledge) in order to **take into account full environmental cycles and to consider social and political issues.**

Challenges and opportunities in China

Wei Ming, China Environmental Science Research Academy, indicated that China now recognises the **need to control pollution, improve water quality and reduce environmental risks.** Pollution limit legislation is currently being developed. Although improvements have started, serious pollution remains in many places and the expected doubling in China's GDP from 2010 – 2015 leads to increasing environmental pressure.

China is particularly looking to implement nitrogen and phosphorus removal technologies, and recognises the **need to recover and recycle nutrients**, as well as addressing heavy metal contaminants in sewage.

Nanqi Ren, Harbin Institute of Technology, explained that China faces water scarcity, with a per capita water availability of ¼ the world average and issues of pollution and below standard tap water. Economic growth and urbanisation accentuate these pressures. However, surface water quality has been slowly improving since c. 2005.

He emphasised that **China has massive opportunities for recovery and recycling from sewage:** 60 mt P (million tonnes), 280 mt N, 100 mt S, as well as energy from sewage digestion (methane), digestion of agricultural wastes (rural China has considerable experience in this), production of hydrogen from biological materials, microbial fuel cells.

ANAMMOX: improving biological nutrient removal

Mark van Loosdrecht, Delft University, The Netherlands, presented a new development in biological nutrient removal processes ANAMMOX, which featured strongly throughout the Conference, in many presentations. This process involves specific types of bacteria which can be developed in sewage treatment plants (in particular in granular sludge, or biofilm set-ups), and which can **convert ammonia NH₄ and nitrite NO₂ to nitrogen (N₂), so avoiding an intermediate step of oxidising to nitrate (NO₃).**

Operated in municipal wastewater treatment plant sludge sidestreams, **ANAMMOX can reduce total sewage plant energy consumption by 2-4%**, through reduced aeration need (the energy saving can be much higher, up to 60%, for industrial wastewaters), reduce the need for organic carbon 'feed' for biological nutrient removal, increase methane energy production potential, improve sewage sludge thickening and dewatering.

The ANAMMOX process has been demonstrated in the Olburgen sewage plant, Netherlands, along with struvite precipitation to enable phosphorus recovery for recycling and improve biological phosphorus removal (c. 500 tonnes of struvite / year). Currently, the application of ANAMMOX in the main stream municipal wastewater treatment is the focus of research

Amongst, the many papers and posters presented at the conference, the following specifically addressed P-recovery and recycling:

Concentrating P by biological routes to enable P-recovery

H. Kodera presented a **biological phosphorus removal system to generate a concentrated phosphate stream** with low organic particle content. Bio-P (phosphate accumulating organisms PAO) were fixed in biofilm in trickling filter columns (2.4 litre volume, 130 cm high), operated in 16 hour cycle batch conditions to achieve the aerobic/anaerobic cycles necessary for biological phosphorus removal, with feeding with organic substrate. Inflow phosphate concentration was 5 mgP/l. This was reduced by 50% by the biofilm reactors, and a 125 mgP/l concentrated

phosphate stream was generated by extraction from the anaerobic phase of the cycle. For the first 90 days of operation, phosphate accumulated in the biofilm, but after that the total P into the system balanced total P out. Some loss of microorganisms from the biofilm into the concentrated phosphate solution occurred. A pilot is now being constructed at Hiroshima sewage treatment works (1 m³/day, 2.4m high columns) and ongoing work aims to minimise microorganism loss to the phosphate solution and to measure consumption of organic substrate.

Q. Tian also presented a similar system, using a **semi-continuously operated biofilter EBPR (enhanced biological phosphorus removal) to generate a concentrated phosphate stream** (released during the anaerobic phase), suitable for struvite precipitation. The concentrated phosphate streams were harvested at 10 days intervals from the biofilter EBPR. An 8 litre capacity, 8 hour cycle biofilter EBPR reactor was tested using synthetic wastewater (80-180 mg COD/l and 8-18 mg soluble P/l). A return loop and a holding tank enabled recycling of phosphate containing liquor released during the intermediate aerobic/anaerobic transition phase. This transition phase P-loss was estimated at 20-30% of influent P and operation with the loop and holding tank, avoiding this loss, increased the EBPR P-removal to 85 – 95%. As biomass accumulated in the biofilter, the EBPR efficiency improved. The effluent collected from the biofilter during the anaerobic phase contained soluble phosphorus at concentrations up to 50 – 200 mgP/l and struvite precipitation showed, as expected, to be more efficient at the higher P concentrations.

Y. Wang presented experimental treatment of sludge from the Xi'an n°4 sewage treatment works, China, using **sludge hydrolysis, struvite nutrient recovery and a Moving Bed Biofilm Reactor for final treatment**. Soluble P and N were released from the sludge by adding an anionic surfactant (SDS) in an anaerobic hydrolysis reactor (batch, residence time 7 days). This results in a supernatant liquor with concentrations of c. 110 mgP-PO₄/l and c. 230 mgN-NH₄/l. 92% P removal was achieved in the struvite precipitation (type of reactor, pH, magnesium dosing not specified). BOD was reduced to around 5 mg/l and P-PO₄ to 0.5 mg/l by the final MBBR step.

Y Chen presented a study of **waste active sludge digestion conditions (at pH 10) with struvite precipitation** to recover released phosphorus and ammonia. Optimal conditions for carbon recovery, short chain fatty acid (SCFA) production to feed biological P removal, and for struvite precipitation were modelled.

M. Chong presented research underway in Australia to compare two different treatment plant configurations for nutrient removal and recovery: **ANAMMOX (anaerobic ammonium oxidation) or CANON (completely autotrophic nitrogen removal over nitrite), both combined with struvite recovery.**

Struvite recovery

Y. Li presented **struvite precipitation from high-concentration pure chemical solutions**: ammonia-nitrogen and soluble phosphate P molar ratio 1:1, 100 up to 1000 mg/l. A fluidised bed reactor with an external clarifier (enabling recycle stream) was used. With a magnesium:phosphorus ratio of 1.1 to 1 and no pH adjustment (pH 7.6), 95% P-removal was achieved, pellets of struvite of up to 4 mm diameter were formed, with no fines formation (whereas fines were found at pH 8.4 or higher).

C. Wang tested **struvite precipitation in a continuous flow laboratory scale reactor, assisted by electrochemical deposition**. The liquor flowed between two horizontal metal electrodes 2 cm apart. Temperature and Mg:P ratio effects were tested. A voltage of 3 – 9 V was shown to improve struvite recovery at pH near neutral and with 70% P precipitation at stoichiometric Mg:P ratio.

P. Schneider presented a **model of a mixed-mode nutrient recovery reactor developed for urine feed**, incorporating complex solution thermodynamics, dynamic conservation equations and a power-law model for crystal growth. EES (Engineering Equation Solver) software was used and comparisons made with PHREECQ modelling. Simulations at nominal operating conditions predict phosphorus recoveries greater than 99%, based on existing process kinetic models. Rates of nutrient recovery depend on the rate of release of the limiting constituent ion, and appear to be insensitive to the amount of seed crystal employed and diurnal feed flow variations of ±50%.

M. Sperandio et al. presented a **model-based approach for designing a struvite crystallisation processes for full scale operation**. Variability of wastewater characteristics mean that design assessment is important before building a full scale installation. The model was developed based on lab-scale batch experimental data, and showed to predict accurately performance of a **continuous mode 150 litre capacity pilot for cheese industry wastewater** containing significant concentrations of whey. Conclusion is that optimal operation is achieved by first increasing pH in an aeration stripper, thus precipitating calcium carbonate, then adding Mg(OH)₂ to provide magnesium and further increase pH for struvite crystallisation.

C. Meyer presented **experience with the “Stuttgart process” pilot plant at Offenburg sewage treatment plant, South West Germany**. The pilot plant is dimensioned to 5% of the sewage works 160 000 pe capacity and has been operating since autumn 2011. The process involves first dissolving the (anaerobically stabilised) sewage sludge at pH 3, then solid/liquid separation (filter press). Citric acid is added to complex heavy metal ions out of the filtrate. The pH is then increased (using NaOH) and magnesium oxide added, to precipitate struvite. The pilot is currently operated in 12 m³ of sludge batches, generating 10 m³ of filtrate containing c. 0.9 kg of soluble phosphorus, generating 63 kg of struvite (that is c. 8 g per capita of struvite).

D. Kruk presented results of **struvite precipitation by electro-coagulation**, using a magnesium sacrificial anode. 1 litre stirred beaker tests were carried out using pure chemical solutions, 3 hour batch runs, 50 - 200 mA current and pH 6.5 – 9.5 Higher currents resulted in improved P precipitation rates and purer struvite, and also in self detachment of struvite deposited on the anode (thus limiting anode passivation).

K. Xu presented **struvite precipitation from source separated urine**, using 500 ml stirred beaker 60 minute batch tests. Phosphate and potassium recovery rates were tested with different magnesium dosages, showing that up to 99% P-recovery and 93% K-recovery are possible.

L. Xavier presented results of **beaker struvite precipitation tests from anaerobic sludge digester supernatant** from a sewage works operating MBBR (moving bed biofilm reactor) in Rio de Janeiro. Increasing pH and magnesium dose both improved phosphorus and ammonium removal rates.

W. Moerman (NuReSys) presented **experience of operation of a full-scale (50 m³/h) P-recovery by struvite precipitation from potato processing factory waste and pilot tests at a sewage works**. The struvite precipitation reactor used consists of firstly an “air stripper” column (hydraulic residence time HRT 10 mins), where aeration takes off CO₂ and so increases pH, flowing into a stirred precipitation reactor (HRT 20 mins), and then finally a settler.

The struvite recovery was installed at the potato factory following severe struvite incrustation of the recycle pump of the UASB reactor used to reduce the organic discharge. The struvite precipitation reactor operated without magnesium addition (potato waste is relatively high in Mg) and at pH8 reached only by aeration CO₂ stripping. Around 60% soluble P-removal is precipitated by the struvite system, with around 70% of the precipitated phosphate integrated into struvite pellets and 30% lost as fines. **The 180**

tonnes/year of struvite produced has been accredited under regional legislation for use as a fertiliser and is sold for c. 75€/per tonne.

A 0.5 m³/h pilot plant was then tested on sludge digester outflow (prior to dewatering) at the Amsterdam Waternet West sewage treatment works. Stable operation was only possible using both strip aeration and sodium hydroxide to increase pH and with a magnesium:phosphorus dosing of 2.2:1. The struvite can be separated from the organic sludge particles using an adapted sandwasher. **This configuration has the advantage of improving the dewatering properties (+2% gain in dry matter content of dewatered sludge)** and the total dewatered sludge quantity for disposal decrease by 10%. Waternet Amsterdam water company is now planning a public tender for the full-scale installation (90 m³/h, approx. 800 – 1000 tonnes struvite per year).

Other P-recovery routes

H. Tsuji used a **layered double hydroxide (LDH) of calcium and iron to adsorb phosphorus** from primary effluent of a municipal sewage treatment works. The synthesised Ca-Fe-LDH showed high selectivity for P adsorption in the effluent, reducing soluble P from 3.2 to < 0.5 mgP/l and taking up c. 100 mgP/g of adsorbent. The Ca-Fe-LDH with adsorbed phosphorus could be used as a fertiliser.

K. Shimamura presented a **calcium phosphate (hydroxyapatite HAP) precipitation process, using polymer dosing to improve HAP granulation**, so accelerating pellet formation and improving settling and so enabling a significantly smaller reactor to be used. A stirred reactor of 700mm inner diameter and 2.8m height, treatment capacity of 200m³/d, was tested on dewatering liquor from a wastewater treatment plant. Ca(OH)₂ was dosed both as a calcium source and to adjust pH. Precipitated phosphate (HAP) and suspended solids were coagulated together into pellets, which were then centrifuge dewatered, dried and furnace sintered (to remove organics). The process reduces suspended solids in the treated wastewater from 590 to 110 mgSS/l and total phosphorus from 46 to 8 mgTP/l. Phosphate content of the final sintered pellets was c. 25% P₂O₅ = 11% P, that is around 80% of commercial phosphate rock. Heavy metal contents were in all cases one or two orders of magnitude lower than authorised limits in mineral fertilisers. See also Shimamura & Kurosawa 2010.

Y. Tang presented phosphate recovery experiments at the laboratory scale, **using anion ion exchangers to selectively adsorb phosphate, followed by membrane electro dialysis cells to regenerate the ion exchange material**. The ion exchangers functioned well with pure phosphate solutions without competing

ions, but efficiency was negatively affected in real sludge liquor in particular because of dissolved organic matter fouling the ion exchangers. The utilization of electro dialysis and bipolar membrane verified the practicability of producing phosphoric acid without dosing extra chemical reagent from the exhausted ion exchange resins, and regenerating the resins simultaneously

Recycling ferric and phosphorus after chemical P-stripping

S. Freguia presented a potentially promising process for **recovering ferric (Fe^{3+} , for reuse in the sewage works for P-removal) and phosphorus (PO_4 solution) from iron phosphate sludge** resulting from the use of ferric chloride dosing for chemical P-stripping. This is probably the first time that a system has been proposed susceptible to achieve recovery of ferric and phosphorus, without the application of prohibitively high temperatures, chemical inputs and extreme pH. To date, the process has been tested at the laboratory scale using pure iron phosphate (FePO_4), with c. 3g ferric (Fe) per batch.

The process, developed by the University of Queensland, Australia, with Veolia Water and Seqwater, uses two stages:

- (1) **sulphide (NaHS)** frees phosphorus from the iron phosphate sludge (releasing PO_4 solution, appropriate for P-recovery) and precipitating iron sulphide (FeS);
- (2) a **reversing electrochemical cell** separates FeS to ferric (for reuse) and sulphur, and simultaneously transforms sulphur back to sulphide for reuse in the process. Because the process operates on the iron phosphate sludge, the liquor volumes will be low, limiting reactor volumes and chemical consumption.

The iron phosphate dissolution (by sulphide) is pH independent, but is optimised at pH4 because this improves FeS settling (because of its colloidal zeta potential), whereas FeS dissolves at lower pH. 72% phosphorus recovery (in the PO_4 solution) was achieved with a stoichiometric Fe:S ratio.

The electrochemical cell had graphite electrodes, separated by membranes. It was batch operated at approx. 1.5 volts. FeS is converted to Fe^{3+} and sulphur is deposited on the anode, whilst at the same time sulphur is converted to HS^- at the cathode. The cell is periodically drained (to recover ferric Fe^{3+} and sulphide HS^-) and then the current reversed, so that the sulphur deposited is re-dissolved. The power consumption was 1 - 2 kWh/kgFe (depending upon the electrochemical efficiency) and is **estimated to cost a**

fraction of sewage works costs for the equivalent ferric purchase and iron phosphate sludge disposal.

Challenges identified include improving the electrochemical availability of the (solid) FeS in the cell, rapid application of the electrochemical process to avoid pyrite (mineral iron sulphide FeS_2) formation, and improving iron and sulphur recycling (objective 90%).

Perspectives for P-recovery

Z. Bradford-Hartke presented a comparative life cycle analysis of different routes for phosphorus recycling: two decentralised options with urine separation, centralised P-recovery via biological or chemical P-removal in sewage works and biosolids use in agriculture, and two applications of struvite precipitation. In this analysis, phosphorus recovery in decentralised systems resulted in a net decrease in global warming potential up to 10 times that achieved in centralised systems, with the savings largely due to avoided power use and greenhouse gas emissions. However, the potential for water and soil toxicity is higher because all wastewater fractions are applied to land. The fraction of plant available phosphorus in biosolids from biological and chemical phosphate removal sewage works can modify the P-recovery value of these options by a factor of 4, and is an important consideration. **Struvite precipitation appears potentially beneficial in most impact categories where centralised sewage collection and treatment is installed.**

C. Thornton discussed **possible drivers and obstacles to P-recovery and recycling**, and possible routes for achieving this. In response to global awareness of the importance of phosphates as an essential, non-replaceable, limited and non-renewable resource, and regional or national concerns about dependence of agriculture and of strategic industries on imported phosphate, some states are initiating policies for P recovery and reuse. Possible routes for recycling phosphates from wastewaters include agricultural valorisation of treated biosolids, use of sewage effluents to feed aquaculture or biofuel crop production, recovery of phosphorus from sewage sludge incineration ash, struvite recovery for recycling as a fertiliser, or other experimental technologies. **The phosphate, fertiliser, waste and water industries have interest to work together to propose appropriate societal frameworks, value chains and technologies**, adapted to specific national or regional objectives of 'closing the loop' for phosphorus and the project for a Global Recycling Institute for Phosphorus is currently being discussed, to provide a centre for information on P-recovery, including economic, industrial, regulatory and societal aspects of implementation, and to provide a voice for and link to

industries interested in developing phosphorus stewardship and recycling.

Calcium phosphate precipitation by bacterial in sludge granules

M. Spérandio presented 250 days operation of a laboratory scale (19 litre volume) **granular sequencing batch airlift reactor (GSBR biological phosphorus removal) where bacteria precipitate calcium phosphate within the granular sludge nodules**. This microbially induced phosphate precipitation (MIPP) generates granules which, after dehydration, with up to **70% mineral content (50% calcium phosphate as hydroxyapatite, 20% other minerals)**. The phosphate accumulation in the granules is due to bacterial action, related to the uptake and release of phosphate and calcium and other ions (resulting in local high concentrations) and to pH changes during the aerobic (pH decrease, P uptake), anaerobic (pH increase, P uptake and release, calcium phosphate formed), anoxic (pH decrease) phases of the bio-P process.

The prolonged retention time within the granules enables the **conversion of initially formed amorphous calcium phosphate (ACP) to hydroxyapatite**, rather than redissolution. Struvite probably forms transiently, but is then redissolved during the nitrification phase, and so does not accumulate. The process offers the advantages of avoiding phosphate release from bio-P sludge and generating granules rich in calcium phosphate, which could be used as fertiliser. However, it requires relatively high calcium concentrations, and calcium may need to be added in some wastewaters.

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“Recovery of carbon, nitrogen and phosphorus from waste activated sludge and applications of recovered carbon source”, Y. Chen, X. Zheng, L. Feng. State Key Laboratory of Pollution Control and Resources Reuse, School of Environmental Science and Engineering, Tongji University, 1239 Siping Road, Shanghai 200092, China yg2chen@yahoo.com

“Integrated and low-cost advanced treatment processes for simultaneous N- and P- removal and recovery from nutrient-rich wastewater stream”, M. Chong (1), B. Jin (2), G. Laera (2), C. Saint (3) and S. Burn (4). 1 = CSIRO Land and Water, Ecosciences Precinct, 41 Boggo Road, Dutton Park, Queensland 4102, Australia 2 = Schools of Earth and Environmental Sciences & Chemical Engineering, University of Adelaide, Adelaide 5005, Australia Bo.Jin@adelaide.edu.au Giuseppe.Laera@adelaide.edu.au 3 = SA Water Centre for Water Management and Re-use, University of South Australia, Mawson Lakes 5095, Australia Christopher.Saint@unisa.edu.au 4 = CSIRO Land and Water, Highett, Victoria 3109, Australia Stewart.Burn@csiro.au

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“Modelling and Dynamic Simulation of a Nutrient Recovery Process”, P. Schneider, J. Wallace, J. Tickle. School of Engineering and Physical Sciences, James Cook University, Townsville, Queensland, 4811, Australia Phil.Schneider@jcu.edu.au

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“Struvite Precipitation Using Magnesium Sacrificial Anode”, D. Kruk, J. Oleszkiewicz d_kruk@umanitoba.ca Dept. Civil Engineering, University of Manitoba, Winnipeg, MB, Canada

“Nutrient Recovery from Source-separated Urine via the Crystallization of Magnesium Potassium Phosphate Hexahydrate”, K. Xu, C. Wang, X. Wang. School of Environment, Tsinghua University, Beijing 100084, China xukangning@tsinghua.edu.cn

“Study of recovery from phosphorus precipitation in line struvite supernatant from anaerobic digester sludge”, L. Xavier (1), V. Isaac (1), M. Cammarota (2), L. Yokoyama (2). 1 = Escola Politécnica, UFRJ, Rio de Janeiro, Brazil. 2 = Escola de Química, UFRJ, Rio de Janeiro, Brazil ldx1982@poli.ufrj.br

“In-line phosphate recovery as nuisance control for struvite clogging sensitive wastewater or sludges”, W. Moerman, NuReSys, Franklin Rooseveltlaan 108, 8970 Waregem Belgium wm@nuresys.com

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“A novel electrochemical process for ferric recycling in chemical phosphate removal”, S. Freguia (1), E. Mejia Likosova (1), Y. Poussade (2), J. Keller* (1). 1 = Advanced Water Management Centre, Gehrmann Labs, Level 6, University of Queensland, St. Lucia, QLD, 4072, Australia. 2 = Veolia Water Australia, Level 15, 127 Creek Street, Brisbane, QLD, Australia and Seqwater, Level 2, 240 Margaret Street, Brisbane, QLD, Australia s.freguia@awmc.uq.edu.au

“A Life Cycle Analysis of three urban wastewater treatment systems being upgraded to achieve phosphorus recovery”, B. Bradford-Hartke (1), J. Lane (2), P. Lant (2), G. Leslie (1). 1 = University of NSW, Sydney, NSW, Australia. 2 = University of Qld, St Lucia, QLD, Australia zenah@student.unsw.edu.au

See also: Coats et al., *Wat. Env. Res.* 83(8) 2011 and Bradford-Hartke et al., *Ch. Eng. Res & Design* 90(1) 2012. **“Parameters controlling calcium-phosphate precipitation in aerobic granular sludge process”**, A. Manas (1,2), M. Pocquet (1), B. Biscans (2), M. Spérandio (1).

“Struvite precipitation from anaerobically digested industrial wastewaters: from lab-scale batch experiment to continuous industrial reactor”, F. Decker (1), M. Simon (3), M. Pocquet (1), M. Spérandio (1)

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P-recycling processes

Potato industry wastestreams

Pilot and full scale struvite recovery

A struvite recovery installation using an aeration stripper column followed by a stirred reactor was first tested in three pilot plants, in three different potato processing factories treating UASB effluent (upflow anaerobic sludge blanket digesters) and then installed in two full-scale installations, dairy industry plant UASB wastewater (results presented) and potato processing UASB plant effluent (started up in 2008, results not yet available at the time of publication).

In all the pilot trials the objectives of reducing discharge phosphate concentrations and avoiding nuisance struvite incrustations were achieved. Operation proved successful and reliable when the calcium concentration and calcium/phosphate ratios in inflow effluent were not too high. High quality, clean and pure struvite granules of 2 – 6 mm were produced. The process is now marketed as NuReSys www.nuresys.org

The process has firstly an air stripper, where pH is increased by aeration stripping of CO₂, followed by a stirred crystalliser reactor, with top entry impeller mixing, baffles and a transient quiescent settling zone. Magnesium chloride and (if necessary) sodium hydroxide (for pH adjustment to pH 8.5 – 8.7) are dosed into the stirred reactor. Recovered struvite is purged from the base of the crystalliser. In all the wastewaters considered, which are from UASB, ammonium is present in excess of phosphate and inflow phosphate is >90% soluble orthophosphate P-PO₄.

The pilot system had a 120 litre stripper tank (aeration at 8 l air/second) and a 200 litre crystalliser tank. Tests were done over a 2 – 3 months period

Operating success dependent on calcium

The pilots showed successful operation in two of the three pilot plant runs, with pilot inflow soluble phosphate concentrations of c. 40 and c. 115 mgP/l, showing 75 – 90 % soluble P removal, but not in the third pilot run with soluble phosphate c. 130 mgP/l (only 20% total P-removal). This pilot had a **higher inflow calcium concentration** (65 mgCa/l) compared to the other two (35 – 40 mgCa/l). The authors conclude that the failure in the third plant is due to calcium either competing to form calcium phosphate instead of struvite, or because amorphous calcium

phosphate flocs prevent agglomeration or growth of struvite fine crystals. The third pilot reactor, it is noted, also needed significantly less NaOH dosing to achieve the target pH.

In the two successfully operating pilot plants, around 20% of the soluble phosphate removal occurred in the stripper tank (80% in the stirred reactor), suggesting that **limited struvite fine formation is occurring in the stripper**, and most of the struvite precipitation is occurring as pellet agglomeration and growth in the reactor. Abrasion by the reactor stirrer will also generate fines to seed pellet formation.

Successful pilot plants

The outflow soluble phosphate concentration was reduced to c. 10 mgP/l in both of the two successful pilots, despite the considerable difference in inflow phosphate concentration. Spherical pellets of pure struvite (confirmed by XRD) were formed, with 98% dry matter after being left to dry in ambient temperatures. Heavy metal analysis showed no detectable contaminants except copper (0.021 g Cu/kg).

Full scale plant

In the full scale plant operating on dairy industry UASB digester wastewater, initial operation achieved 70-75% P-removal, but produced no struvite formation was detected. This was thought to be the consequence of high calcium in the wastewater (140 mgCa/l) and low soluble phosphate (40-45 mgP/l). A change in UASB operating conditions led to an increase in soluble phosphate (to 65 mgP/l) and under these new conditions, struvite was successfully produced, generating 2-6 mm struvite granules, with only c. 16% of phosphate removal attributable to amorphous matter.

The authors conclude that successful operation depends both on the absolute calcium concentration in treated liquor not being too high, and on the calcium/phosphate ratio.

They note that **the effectiveness of top-entry stirred reactors is proven**, and that these offer flexibility in mixing speed and reagent injection points.

The struvite pellets produced were of high quality, pure and without any significant contaminants, self-dried easily, and could be a valuable fertiliser.

“Phosphate removal in agro-industry: Pilot- and full-scale operational considerations of struvite crystallization”, *Water Research* 43, pages 1887-1892, 2009
www.elsevier.com/locate/watres

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See also: SCOPE Newsletter n°74 (page 4) and “Full-scale modelling of a food industry wastewater treatment plant in view of process upgrade”, A. Vandekerckhove, W. Moerman, S. Van Hulle, *Chemical Engineering Journal* 135, pages 185-194, 2008
www.elsevier.com/locate/cej

Composting

Struvite and NO_x emissions

Nitrogenous emissions during composting cause odour problems, reduce the fertiliser (N) value of the compost and contribute to greenhouse gas emissions. This paper presents testing of approaches to reduce nitrogenous emissions from swine manure composting: struvite precipitation (by soluble phosphorus P and magnesium Mg addition) and this plus addition of nitrite oxidising bacteria (NOB).

The experiments used raw pig faeces mixed with sawdust (to render appropriate for aerobic microbial degradation), initial bulk density 0.5 kg/l, composted in specifically designed 32 and 100 litre laboratory composting chambers, with controlled air inlets/outlets, for 76 – 91 days. Airflow was 0.6 and 1.7 m³/h for the smaller and larger chambers respectively.

Compost temperature and air outflow NH₃, N₂O and NO_x were measured. The compost was turned to ensure mixing every 1-3 weeks, and at the same time sampled for analysis. Condensate water was returned to the compost in order to not lose dissolved nitrogen.

Reducing nitrogen losses

In the struvite precipitation experiments, magnesium (as MgCl₂) and phosphorus (as H₃PO₄) were added as solutions in water at the start of composting at doses of 0.045 and 0.030 mol/kg faeces. These doses were based on previous work (Jeong & Hwang 2005, Lee et al. 2009) suggesting these to be optimal doses: higher doses increased struvite precipitation, but also reduced the composting of organic matter and increased reagent costs.

Nitrite oxidising bacteria (NOB) came from a >6 month old composting pile (non-aerated, frequently turned) and were added to the experimental composting chambers after the thermophilic phase of composting.

Nitrogen loss in the control experiments was 28-30%, reduced to 15% in the experiment with struvite precipitation (P and Mg addition), that is a 51% reduction in nitrogenous emissions, and to 11-12% in the experiments with both struvite precipitation and NOB (60% reduction in nitrogenous emissions). NO₃ emissions were reduced by 25-43%.

The **presence of struvite** was estimated by comparing NH₄-N after 0.5 mol/l HCl extraction (method from Tanahashi et al. 2010) and then 2 mol KCl. This suggested that struvite was indeed formed in the experiments where P and Mg were added, but that struvite re-dissolved (disappeared) with the addition of NOB.

This is considered by the authors to probably be because the pH drops significantly (with NO₃ accumulation). This means that although the P and N in the compost may be of lower agronomic value because they are not in the form of the slow-release fertiliser, struvite.

“Effects of struvite formation and nitrification promotion on nitrogenous emissions such as NH₃, N₂O and NO during swine manure composting”, Bioresource Technology 102, pages 1468–1474, 2011: www.elsevier.com/locate/biortech

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Dairy manure

Using magnesium to precipitate calcium phosphate

Flushed dairy manure wastewater was collected from the Dairy Research Unit of the University of Florida, after mechanical solids separation and solids settling. Phosphate precipitation was then tested in four 1-litre fluidised bed reactors, continuously operated in parallel. Two different seeds were tested (quartz sand and periclase = magnesium oxide MgO), pH increase (NaOH) and magnesium sulphate (MgSO₄) dosing. The magnesium addition was considered to inhibit calcium carbonate (CaCO₃) precipitation, and so facilitate calcium phosphate precipitation.

The lab-scale reactors used were one-litre cones, with 2 litre/minute influent flow injected into the reactor base (30 second hydraulic residence time), with an initial 20g of seed material. Four such reactors were operated in parallel for 2.5 hour runs.

The manure liquor contained 19 – 26 mg/l P, 116 – 166 mg/l Ca, 58 – 69 mg/l Mg, 233 – 258 mg/l K and

135 – 156 mgNH₄/l (all as soluble ion concentrations, not total concentrations).

XRD, SEM and EDS analysis showed that the precipitate was poorly crystalline hydroxylapatite (calcium phosphate).

Magnesium addition

Magnesium dosing, in both the manure wastewater reactors and in a pure solution experiment, showed to effectively enable calcium phosphate precipitation. The authors suggest that this is because the magnesium reacts rapidly with bicarbonate ions, to form MgCO₃, thus preventing the bicarbonate ions interfering with calcium phosphate precipitation.

The results show that high pH is necessary for calcium phosphate precipitation from this manure liquor (pH 8.5 – 9.5), that the magnesium addition considerably improved phosphate precipitation, whereas the choice of seed material in this case did not have a significant impact. With magnesium addition (at a ratio of Mg/Ca > 0.1) and pH around 9, up to 80% of soluble phosphate was precipitated.

“Bench-scale recovery of phosphorus from flushed dairy manure wastewater”, Bioresource Technology 99, pages 3036–3043 (2008) <http://www.sciencedirect.com/science/journal/09608524>

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Crab shells, mussel shells

P-recovery by adsorption to shells

In SCOPE Newsletter n°84, a number of papers testing phosphorus adsorption by different seafood waste shells showed that calcination was necessary (converting calcium carbonates in shells to lime CaO) and that particle size and surface characteristics were also important. These papers present further laboratory tests using calcinated mussel shells and uncalcinated crab shells.

Mussel shells

Xiong et al. tested **freshwater mussel shells produced as waste by cultured pearl production sites** in Chuzhou City, Anhui Province, China. Phosphate removal from potassium phosphate solutions was tested at different phosphate concentrations, ionic strengths (addition of potassium chloride), pH and reaction times. Untreated shells (crushed, sieved, dried) were compared to calcinated shells (700°C for 20 minutes).

P-removal showed to be much better with the calcinated shells (55% at pH 5) compared to the untreated shells (25%).

P-recovery

The calcinated shells adsorbed 0.987 mgP/g and the untreated shells 0.979 mgP/g. Shaking in 2% citric acid for one hour released 85% of the adsorbed phosphate from the treated and 97% from the untreated shells, suggesting a possible route for phosphorus recovery and recycling.

Crab shells

Jeon and Yeom tested **non calcinated crab shells (main crust and legs) collected from restaurants** in Gangneung City on the East Sea, Korea. The shells were washed, dried, ground and sieved to various particle sizes, then tested for P-removal from sodium phosphate solutions.

Crab shells are composed of calcium carbonates, but also over 50% organic molecules including chitin and other proteins and cellulose. The main crust shells contained c. 1% phosphorus (P) and the legs c. 2% P. In preliminary tests, the main shells showed better P-removal than legs, and so the legs were not then used in further tests.

Test results showed that **optimal P-removal was achieved with small shell particles**, and that P-removal could be achieved at a range of different pH values. Maximum P adsorption capacity was estimated to be c. 110 mgP/g, that is significantly higher than other (non calcinated) shells.

Prior treatment of the shells to selectively remove calcium, protein or cellulose suggested that calcium carbonate, protein and carbon backbone were respectively accounting for 46%, 20% and 26% of the shell's phosphate adsorption.

Non calcinated crab shell particles of < 1mm diameter showed > **85% P-removal** from 500 mgP/l phosphate solution.

"Phosphate removal from solution using powdered freshwater mussel shells", Desalination 276 (2011) 317-321
www.elsevier.com/locate/desal

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"Recycling wasted biomaterial, crab shells, as an adsorbent for the removal of high concentration of phosphate", Bioresource Technology 100 (2009) 2646-2649,
www.elsevier.com/locate/biortech

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P-recovery route assessments

Netherlands

Assessment of options for P-recovery from manures

Animal manure production in The Netherlands is expected to exceed limits for agricultural spreading by 15 – 20 000 tonnes P in 2015. This study assesses technical and agro-economic perspectives for treatment routes for manures to enable phosphorus recycling. Processes considered include anaerobic digestion, solid-liquid separation, ultra-filtration and reverse osmosis treatment of the liquid fraction, drying, composting, pyrolysis, incineration, use of manure products in the phosphate or fertiliser industry as a raw material, and phosphate precipitation for P-recovery.

Phosphorus recycling from manures is always part of an overall treatment process. A first step can be anaerobic digestion, either of whole manure or of the solid fraction only. **Some 20 – 30 m³ of methane can be generated per m³ of manure.** Based on experience with the production of biogas from sewage sludge this amount can probably be increased to 35-40 per m³ manure if an appropriate pre-treatment is applied. Solid liquid separation

A range of technologies can be used to separated manure into a liquid fraction and a wet solid cake: centrifuge, filter presses, sedimentation, air flotation, straw bed filter ... Coagulants and flocculants are generally used to improve separation, but this increases cost.

The solid manure fraction can be dried to enable storage and transport, and so recycling to agriculture in regions where it can supply nutrients to crop needs. However, this consumes energy and generates polluted off-gases (ammonia, dust, ...), which require treatment.

Pyrolysis, gasification, incineration

Pyrolysis involves treating the manure at 350 – 500°C without oxygen, so that organic compounds are broken down. Approx. 60 – 70% of the initial organic carbon remains in the biochar produced, much of the rest goes to syngas (a mixture of methane, hydrogen and carbon monoxide) which can be burnt to produce electricity, and some to pyrolysis oil.

Gasification acts similarly, again without oxygen, but at 800 – 1000°C, leaving only around 10% of initial organic carbon in the char. In both cases, energy conversion via syngas is more efficient than through incineration, and the nutrients in the char are more readily plant available than in incineration ash (in particular phosphorus). Phosphorus remains more available in pyrolysis char, because of reactions with silicates and metal oxides at higher temperatures. Biochar can either be used as a soil amendment, providing fertiliser nutrient value, or incinerated for further energy recovery.

Incineration offers lower energy recovery, and dioxin and furan emissions in the exhaust gases have to be prevented. Because of cost, incineration is only feasible at a large scale, or in co-incineration with other wastes.

Manure incineration ash is considered to not be useful as a fertiliser, because the nutrients are not available, but can be used to substitute phosphate rock in the phosphate industry (at the Thermphos International site, Vlissingen, The Netherlands) or the fertiliser industry (eg. AMFERT, ICL Fertilisers, The Netherlands). However, **this requires low levels of iron (no use of iron chemicals as flocculants)** and specific limits for other elements such as copper or zinc. Recovery of phosphate from incineration ash is also possible through acid extraction processes, but the economic feasibility of these is not demonstrated to date.

Liquid fraction

The authors note the risk that the liquid fraction of manures is often not adequately managed, because it contains no energy value and low nutrient value. Colloidal carbon in the liquid fraction can be reduced by appropriate choice of coagulants and flocculants prior to solid-liquid separation.

Phosphate can be significantly reduced in the liquid fraction by precipitation of calcium phosphate, struvite or K-struvite and the recovered phosphate (and possibly some potassium and nitrogen) can be recycled as a fertiliser or added back to the solid fraction. Ammonia treatment remains necessary, either by stripping or recovery as ammonium sulphate.

Ultra filtration (through a membrane) can be used to separate out colloids and large molecules, or reverse osmosis can be used to produce purified water and a concentrate of nutrients from which recovery is possible. However, both of these technologies pose questions of cost and of long-term reliable operation in real manure treatment conditions.

Phosphorus recovery from manures can also be achieved by **hydrolysis of the solid fraction, to release a maximum of phosphorus** into liquid as soluble inorganic phosphate, followed by phosphate precipitation as calcium phosphate or struvite. Solid – liquid separation is usually necessary if the objective is to recover a pure phosphate for sale as a fertiliser.

Assessment

Cost assessment estimates are given for the different treatment route options, taking into account energy consumption and energy recovery, and phosphate recovery valued at zero to 5x phosphate rock price. **The total value of energy and nutrients in pig manure is estimated at 6 – 11 € per m³**, whereas treatment costs are estimated per m³ at 24 – 31 € for pyrolysis/gasification, 2.5 € for solid-liquid separation, 6-8 € for transport, 5-8 € for drying and 11 – 14 € for treatment of the liquid fraction. The overall process economics will depend partly on future energy and phosphate prices, but mainly on local conditions specific for each manure producer such as regional nutrient needs, transport costs, possibilities for joint investment with treatment of other wastes.

The cheapest option for ‘dealing with manure’ is to reduce the nutrient content of manures produced, by changing animal feed methods and diets.

Mechanical solid – liquid separation appears as a low cost, low technology, no regrets option, which increases the flexibility of treatment and disposal of manures.

The authors note that existing technologies and routes could deal with The Netherlands existing and forecast manure surplus, enabling phosphorus recovery and recycling, but that **this implies significant cost, and organisational efforts to coordinate farmers, intermediaries, waste treatment companies and industries able to recycle phosphorus.**

“Phosphorus recovery from animal manure. Technical opportunities and agro-economical perspectives”, Alterra report 2158, Wageningen 2010 <http://edepot.wur.nl/163684>

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Comparative goal-oriented LCA

Assessment of sewage sludge treatment considering P-recycling routes

This assessment compared P-recycling through sewage sludge disposal by application on farmland (after lime stabilisation), mono-incineration (dedicated sewage sludge incinerator) then farmland spreading, mono-incineration then landfill, co-incineration in cement works, co-incineration in a coal-fired power station, and mono-incineration then SUSAN / ASH DEC P-recycling technology of incineration ashes. The comparison looked at materials and energy flows, human health and environmental indicators, conservation of resources and statistical entropy analysis (quantification of the concentration and dilution / dissemination of different substances).

The comparative assessment assumes that raw sewage sludge has a dry matter content of 4.2%, with organic and inorganic fractions of 68% and 32%. 50% of the raw sludge undergoes digestion, and sludge is mixed and dewatered to 24% dry matter content.

Different sludge disposal routes

Where sludge is **spread on farmland**, the study assumes stabilisation by addition of quick lime (CaO) (30% of dry matter). The phosphorus in sludge is assumed to be 60% soluble in citric acid, with plant utilisation of 2/3 of soluble phosphorus.

Where sludge is **mono-incinerated**, prior additional dewatering is assumed (to 40% dry matter, using waste heat from electricity generation), and mono-incineration then considered to be carried out in a fluidised bed furnace at 900°C.

For **co-incineration in cement production or coal-fired power stations**, dewatering to 90% dry matter is assumed. The use of max. 5% sewage sludge input to total clinker produced is assumed in cement works. In these scenarios, phosphorus is effectively 'lost' to the cement clinker or power station ash (assumed to be used in building materials), and heavy metal contaminants are mostly fixed there too.

The SUSAN / ASH DEC process (see SCOPE Newsletter n° 78 and Mattenberger et al. in this Newsletter) involves mono-incineration then **processing of the sludge incineration ash by mixing with a chlorine donor chemical (e.g. calcium or magnesium chloride) then heating to 850 – 1000°C**. This removes c. 90% of cadmium, copper, mercury and zinc from the ash, and render the phosphate more bio-available.

Environmental impacts

Heavy metal emissions to air, water and soil were compared, and the overall impact assessed using the **IMPACT 2002+ and CML models**. These give significantly different results, with for example copper and zinc dominating terrestrial ecotoxicity in IMPACT 2002+, whereas chromium dominates for this compartment in CML.

Also, the accumulation of heavy metals in agricultural soils is assessed. **Mercury appears as the element of most concern for direct agricultural use of sewage sludges**. In reality, this will depend very strongly on the actual content of different heavy metals in a given sewage works, which can vary considerably.

Heavy metal accumulation in agricultural soils is considerably reduced by the SUSAN / ASH DEC technology, compared to direct spreading of biosolids.

NO_x emissions and primary energy balance were estimated for the sludge incineration/treatment processes, for transport to spreading or treatment site, and for chemicals used (such as quick lime). **Transport did not appear to be a significant factor**. NO_x emissions were significantly higher for the cement and coal power routes, largely because of the lower air pollution control standards for these industries. **The energy balance is best for the direct agricultural spreading route**, whether or not transport energy consumption is taken into account. Incineration in coal fired power production gives the most negative energy balance.

Phosphate recovery

Phosphorus recovery was estimated for the three scenarios with farmland use (biosolids spreading, mono-incineration and spreading of ash, SUSAN) by calculating the % of sludge phosphorus going to spreading and the citric acid solubility of the phosphorus in the spread product. In the mono-incineration plus landfill, cement and coal power scenarios, there is zero phosphorus recycling.

The paper concludes that agricultural spreading of stabilised sewage sludge offers optimal energy balance and good phosphorus recycling. The latter is however only true if the sludge is used on fields where crops need phosphate input, to replace phosphate fertiliser, and not simply spread within 'disposal limits' on land near to sewage works in order to minimise transport costs. The SUSAN / ASH DEC process performs optimally as regards environmental protection and resource conservation, but with a higher energy consumption.

The authors underline that this study **does not take into account organic contaminants in sewage sludge**, which pose possible environmental and health problems for agricultural sludge spreading, and that it does not take into account the phosphate or nitrogen fertiliser use 'economised' by recycling of sewage biosolids or recovered phosphate products. This has considerable implications not only for resource consumption, but also for energy consumption and heavy metal dissemination (production of nitrogen fertiliser, processing and transport of phosphate rock, heavy metal contaminants from phosphate rock found in mineral fertilisers).

"Comparative goal-oriented assessment of conventional and alternative sewage sludge treatment options", *Waste Management (Elsevier)*, n°30, pages 1043–1056, 2010
<http://dx.doi.org/10.1016/j.wasman.2010.02.025>

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Review

Summary of P-recovery routes

The authors outline the high cost and disposal problems associated with chemical dosing for removing phosphorus from wastewaters. As a complement to biological phosphorus removal systems, new and more sustainable chemical processes for phosphorus removal from wastewaters are emerging, including filtration by chemically-reactive materials, adsorption and precipitation of minerals (e.g. struvite). These processes are intimately linked to wastewater biology, because this governs chemical properties such as pH, redox potential and conductivity, all of which affect phosphorus removal processes.

Filtration

A number of locally available and low-cost materials have been tested by different researchers for P-removal by chemical filtration, including **iron or calcium-rich slags, calcium silicates, oil shale ash, zeolites, and biological materials such as shells, maerl, marine plant fibres and water hyacinth straw**.

Use of such materials for P-removal is generally suited to smaller waste water treatment plants, because of the size of the filter bed necessary to ensure sufficient contact time. For some of these materials, regeneration has been demonstrated (thus making P-recovery possible), but this requires aggressive chemicals (acid, alkali) which pose cost and management barriers.

Further research to find more benign regeneration chemicals is needed.

Where regeneration is not carried out, **phosphorus can be recycled when natural materials are used for adsorption** through use of the P-enriched adsorbent as a fertiliser or soil amendment, but this is not the case for waste materials (such as slags) which may contain contaminants.

Polymers, nanomaterials

New polymers and nanomaterials offer potential for enhanced phosphorus removal, either by **improving the efficiency of P-removal by other materials, or by direct P-uptake themselves** (e.g. P-adsorption into polyallyl hydrochloride gels).

Struvite

Considerable recent R&D has investigated P-removal from different waste streams by **chemical struvite precipitation**.

It is known that **bacteria can also induce struvite precipitation**, but there has been little research on possible application of this in wastewater treatment.

The authors also consider that further investigation is needed into the characteristics of recovered struvite which affect its value and user-uptake as a fertiliser: particle size, morphology, purity and contaminants (levels of heavy metals, whether or not pathogens are retained in struvite).

The authors conclude that a better understanding of **how these different chemical P-removal processes combine with biological processes** and conditions in waste water treatment plants is needed to improve efficiency, and that future research needs to take into account the objective of not only removing phosphorus but also recovering and recycling this vital element.

"Biologically and chemically mediated adsorption and precipitation of phosphorus from wastewater", *Current Opinions in Biotechnology*, 2012 – 23 in press
<http://dx.doi.org/10.1016/j.copbio.2012.07.003>

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Brussels, 6-7 March 2013

European Sustainable Phosphorus Conference

<http://www.espc2013.org/>

Frontrunners from several European Member States have joined forces to raise awareness about the necessity for more sustainable phosphorus management. The ambition is to create a clear and coherent legislative framework for eco-innovation, a sustainable European market for secondary phosphorus and more efficient phosphorus use.

- Raise awareness about the necessity for more sustainable phosphorus management within the context of a **Resource Efficient Europe**.
- Create support for a clear and coherent **legislative framework**, to create an enabling environment for eco-innovation, a sustainable European market for secondary phosphorus and more efficient phosphorus use.
- The further development of **sustainable nutrient chains** within Europe. Connecting different nutrient waste flows and market possibilities between stakeholders (private sector throughout different sectors, knowledge institutes, government and NGO's) within the EU.

Monte Carlo, 25-27 March 2013

Phosphates 2013

<http://www.crugroup.com/events/phosphates/>

The CRU Phosphates conferences are the only global meeting for the worldwide phosphate industry (rock production, fertiliser, animal feeds, food, detergents, other industrial uses).

These conferences bring together over 500 delegates from tens of countries worldwide, including senior industry executives and organisations that define phosphate supply and demand. Phosphates 2013 will provide a macro view of historical and current **markets, supply, demand and prices** to better understand the context for future trends.

Beijing, 18-20 June 2013

Global TraPs world conference

www.globaltraps.ch

The **Global Transdisciplinary Processes for Sustainable Phosphorus Management** (Global TraPs) project is studying phosphorus use, management and sustainability from a supply chain perspective involving academia, industry, governments, NGOs and other concerned parties (see SCOPE Newsletter n° 86).

The conference theme is “**Learning from Case Studies – Exploring Policy Options.**” with the objective of assessing specific areas for policy intervention to ensure sustainable phosphorus use in the future.

The conference will be co-hosted by China Agricultural University, Ministry of Agriculture, Chinese Ministry of Education, Phosphorus Fertilizer Industry of China, National Science Foundation of China, IFDC, Fraunhofer Institute and other Institutes.

The Conference will coincide with the **5th International UNEP Global Platform Nutrient Management Symposium**

Vancouver, 28-31 July 2013

International Nutrient Removal and Recovery Conference

<http://www.wef.org/nutrients/>

Combined WEF and IWA-NRR conference: **Nutrient removal and recovery 2013 – trends in resource recovery and use.**

Call for abstracts (for papers and posters) is open until 12th December 2012 on categories including:

- **nutrient recovery processes**
- **nutrient recovery from source-separated urine and agricultural effluents**
- **nutrient management of biosolids**

Conference organised by WEF (Water Environment Federation), IWA (International Water Association), WERF (Water Environment Research Foundation) and British Columbia Water & Waste Association.



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