
SCOPE NEWSLETTER

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Special : P-recovery seminar summary

Seminar

German Environment Agency (UBA) p2

A seminar organised by Germany's Federal Environment Agency UBA and the Aachen Institute for Water Management RWTH addressed a wide range of issues concerning phosphate resources, plant and crop needs, phosphorus fate in the landscape and technical perspectives for P recovery and P recycling.

Phosphorus recycling

Phosphate removal

P-release in biological P-removal p6

10-25% of phosphorus in sludges from biological P-removal plants can be released during digestion, generating a significant return of soluble phosphates to the sewage works head and reducing P-removal effectiveness. The authors suggest that this release can be kept below 10% by appropriate sludge management.

Scaling

Preventing struvite precipitation p8

Struvite precipitation offers a route for recycling phosphorus from sewage, but can also cause significant scaling problems in waste water treatment works. The effects on struvite precipitation of 4 anti-scaling products and chelating agents were tested.

The Netherlands

Biological P-removal for sustainability p9

Summary text for front page
Integrated design of biological phosphorus and nitrogen removal sewage works can minimise energy production and CO₂ emissions, enable phosphorus recovery, and enable strict discharge limits to be met.

Nutrients and ecosystems

Sweden

Variations in benthic algae

A study of benthic algae in Lake Erken, Sweden, showed considerable variability in algal biomass at many different sites over the areas of the lake, apparently not related to the local nutrient status.

Call for Papers:

**STRUVITE:
its role in phosphorus recovery
and reuse**

**International Conference
Cranfield University, England,**

17-18 June 2004

**Authors are invited to submit an extended abstract
(up to 2 pages) by 30th March 2004.**

**Travel and conference costs for selected speakers
will be covered by the organisers**

Selection of papers:

* The conference covers themes from struvite precipitation chemistry, through experience of struvite recovery units operating in sewage and animal waste streams, to the value of struvite as a fertiliser (see conference flier)

* Extended abstracts must be submitted by email to struvite@cranfield.ac.uk by 30th March 2004: maximum 2 pages including figures etc. References of previous published papers should be included.

* Papers will be selected by the Conference Organisers for acceptance for presentation at the conference and for selected papers for travel and conference cost coverage. Priority will be given to papers presenting practical experimental or pilot scale experience and results.

* Authors will be informed by 30th April as to whether their paper has been accepted and whether cost contribution is possible

* Papers selected to be presented at the Conference should be submitted as full manuscripts (max 8 pages) in "Water Science and Technology" format by 30th May. These will be reviewed and selected papers will be published in this Journal.

Further information:

<http://www.cranfield.ac.uk/sims/water/struvite/>

Special :
P-recovery seminar summary

Seminar

German Environment Agency (UBA)

The German Federal Environment Agency UBA seminar on phosphorus recovery for recycling in February 2003 brought together around one hundred experts, regulators and water industry operators (SCOPE Newsletter n° 52). The Conference led to the announcement by UBA of phosphorus recovery as a national objective (see <http://www.nhm.ac.uk/mineralogy/P-recovery/UBApressrelease.doc>).

The 2001 Annual Report of the German Federal Environment Agency (UBA) stated: "In the context of new orientations for waste management, it is planned to initiate cycling for phosphorus. Phosphorus containing wastes include sewage sludge, animal and poultry wastes, slaughter wastes, human and food wastes. After separative incineration, the phosphate content from these wastes can be recovered for recycling. Today, phosphate fertilisers are exclusively manufactured from mineral phosphate rock. Inevitably, this raw material will progressively become scarcer and more expensive globally. The element phosphorus is an essential plant nutrient which cannot be substituted by any other element, and is therefore vitally important for crop production. Therefore, technology development should rapidly be launched to recover phosphorus from domestic phosphate-rich waste streams in order to produce fertilisers which offer both hygiene safety and plant availability and efficiency of nutrients."

The Berlin 2003 seminar presentations have been published and include 18 papers, mainly in German.

The first papers look at availability of phosphorus resources and use of phosphorus by plants.

E. Schnug gave a detailed balance of the pathways for P in soils, the short- and long-term availability of fertilizers, and the amounts of P needing to be added to soils in Germany, questioning whether soils need over the long term the levels of phosphate addition they are currently receiving.

D. Pradt (Agricultural Industry Federation, Frankfurt) indicated that existing known mineral rock reserves amount to around 12 billion tonnes, with estimated as yet unexplored reserves of a further 22 billion tonnes, compared to consumption (2001) of around 126 million tonnes. The agricultural mineral fertiliser industry uses 80-90% of world phosphate production. Resources are thus finite but not rare, but 75-80% of (known – unexplored) reserves are held by only three countries: Morocco, Jordan and South Africa. Sources of recovered phosphates must fulfil criteria of quality, logistic availability and public acceptance, and if these conditions are met, may be used by the fertiliser industry.

W. Römer (Georg-August University, Göttingen) presented experiments into plant uptake of phosphorus from soils treated with sewage sludges containing different iron:phosphorus (Fe:P) ratios. He concluded that Fe:P ratios > 1.4:1 resulted in significantly reduced plant phosphorus uptake and even would fix and render unavailable for plants both existing soil phosphorus or phosphorus added in fertilisers.

H-G. Frede and M. Bach (Giessen University) presented a simplified balance of agricultural phosphorus flows in Germany (2000). This can be interestingly compared with the complete P-balance (all uses, including domestic and agriculture) prepared for The Netherlands by Fong, presented by Van Ruiten 1998 (See <http://www.nhm.ac.uk/mineralogy/phos/manure.htm>) The authors show that Germany imports 196,000 tonnes of phosphorus per year (tP/y) into agriculture, plus inputs of 61,000 tP/y from domestically grown animal food crops. Net excess phosphorus from German agriculture is 166,000 tP/y, susceptible in time to be lost from soil to surface waters. *SCOPE Newsletter authors note:* this agricultural excess can be compared for example with an estimated use of phosphorus in dishwasher detergents in Germany of 20,000 tP/y (derived from AISE 1999 data).

P-recovery techniques

A number of authors presented different proposed **systems for extracting phosphorus from waste streams in a recyclable form.**

Ruckert et al. (Fraunhofer Institute) presented a process for treating manures to produce biogas

SCOPE NEWSLETTER

(methane), compostable solids and then (after ultra-filtration and reverse osmosis) precipitation of phosphorus as struvite (magnesium ammonium phosphate MAP). This process has previously been described in English at the [Second International Conference on Phosphorus Recycling](#) (Noordwijkerhout, 2001) and a full-scale pilot plant is now operational in Belgium (see [SCOPE Newsletter n° 52](#) page 4).

U. Brüß (A3 GmbH, Gelsenkirchen) proposed struvite MAP precipitation from manures after biogas production, settling/solid separation, ultra-filtration, with membrane clarification and reverse osmosis as final steps after the phosphate precipitation.

G. Kley et al. (German Federal Office for Materials Research and Testing – Bundesamt für Materialforschung und –prüfung – BAM, Berlin) discussed possibilities for P recovery for recycling from sewage sludges and manures by thermal processes. The authors present analyses of ash from incineration of different sewage sludges (Schirmer, 1998) showing phosphate contents (P_2O_5) varying from 9.9 – 19.3% (that is 3.7 - 7.1 % P) and from animal manure incineration of 27.7% P_2O_5 (10.2% P) (Feistel). The sewage sludge ashes show iron levels of up to 20% (Fe_2O_3), copper up to 0.012% (Cu) and zinc up to 0.039% (Zn) which could prove to be obstacles to recycling in the phosphate industry (see [Schipper et al.](#) at the [Second International Conference on Phosphorus Recycling](#) Noordwijkerhout, 2001) <http://www.nhm.ac.uk/mineralogy/phos/Nordwijkerhout/Schipper1704.doc> The authors suggest thermal treatment with alkaline earth chlorides to evaporate the heavy metals from the ash. They also suggest thermal treatment with sulphate of meat and bone meal ash to improve the availability of phosphate to plants.

J. Rogasik et al. (German Federal Office for Land Economy - Bundesforschungsanstalt für Landwirtschaft, Braunschweig) also gave figures for the P content of incineration ashes from animal manures and sewage sludge, as 18.6% and 3.6%P respectively (I. Rosyadi, 2003, unpublished). Rosyadi also showed that the plant availability of phosphorus can be improved by inoculation of *Thiobacillus* and elemental sulphur.

K. Fricke (Braunschweig Technical University) and **W. Bidlingmaier** (Bauhaus University Weimar) indicated that effective usability of phosphate rock resources depends on the ratio between phosphorus and cadmium, and that P-recovery from organic wastes offers the benefit of providing a P-resource with low cadmium levels. They presented an assessment of arisings of different phosphorus-containing wastes for Germany, taking into account realistically feasible levels of collection, giving the following **annual arisings potentially available for recovery for P-recycling**:

(in tonnes P/year):

* organic part domestic refuse,	
food wastes	6,425
* garden/park wastes (woody)	717
* garden park wastes – other	3,466
* sewage sludges	31,185
* slaughter house wastes	5,460
* food wastes, wine industry, fruit, paper wastes, etc	1,120
* wood bark	945
TOTAL	49.316

Certain slaughter house wastes subject to specific regulations requiring their hygienic disposal are not included. The authors reach a total of 49,316 tonnes P/year. SCOPE Newsletter authors' note: the above figures do not include phosphorus arisings in agriculture: crop wastes, animal manures from livestock and poultry production.

N. Jardin (Ruhrband, Essen) presented detailed information concerning phosphorus flows into and through sewage treatment works and implications for phosphorus recovery (see also his [previous paper in English](#) at the [Second International Conference on Phosphorus Recycling](#) Noordwijkerhout, 2001). For 2002, he estimated (UBA Umweltbundesamt 1999 "[Nährstoffbilanzierung des Flussgebiete Deutschlands](#)" 75/99) the average domestic phosphate load to sewage works as 1.9 gP/person/day, of which detergents (dishwasher) around 0.3gP/person/day. The phosphorus loads from households to municipal sewage works in Germany were thus around 51,500 tonnesP/year (74.2 million persons connected to sewage works), to which an additional 40% (+19,600 tP/y) from industry were added, giving a total of 72,100 tP/y reaching municipal sewage works.

SCOPE NEWSLETTER

A 1999 survey suggested that 92% of the German population was then connected to sewage works, with phosphorus being removed to below 1 mgP/l (annual average) for 79% of waste waters being treated. Consequently, phosphorus emissions from German sewage works to surface waters had been reduced by 80% (1983-1985 to 1993-1997), down to 11,350 tP/y (that is 16% of sewage works inflow phosphorus as estimated above).

Jardin provides (reference UBA as above, 1999) a **breakdown of phosphorus inputs to the environment in Germany for 1993-1997:**

	(in tonnes P/year):
* municipal sewage works	11,350
* industrial discharges	1,250
* storm and sewage overflow	2,570
* erosion, drainage water, underground water, and other diffuse sources	22,070
TOTAL	37.240

Jardin then presented material flow balances for phosphorus in different types of sewage works configuration. In a conventional sewage works (without nutrient removal) he suggested that the inflow phosphorus will go 11% to primary sludge, 37% to secondary sludge, leaving 52% in discharge water. Where simultaneous chemical P-stripping is installed, 11% of inflow phosphorus continues to go to primary sludge, but now 79% goes to secondary sludge (37% in organic form, 42% as insoluble precipitate), leaving only 11% in discharge. Where biological P-removal with chemical “finishing” is installed, the same figures were given, but with only 5% in insoluble form in the secondary sludge.

Jardin concluded that **around 90% of input phosphorus in sewage works is potentially available for recovery from sewage sludge or from sewage sludge incineration ash**, that is around 64,000 tonnesP/year for Germany – corresponding to some 43% of national mineral phosphate fertiliser use.

T. Buer and D. Montag (RWTH Aachen) took a somewhat different premise, suggesting that only the phosphorus removed in sewage works but not transferred to primary or excess secondary sludge, that is 33-67% of inflow P, would be available for phosphorus recovery processes operating within the sewage works. They discussed configurations for

integrating P-recovery into sewage works using chemical or biological P-removal, and presented a number of possible technical processes for phosphorus recovery for recycling (including cost estimations for each): calcium phosphate precipitation, ***BioCon process*** (P-recovery from sludge incineration ash), struvite precipitation from sludge filtrate. A more detailed paper is available at: http://www.isa.rwth-aachen.de/docs/wiss_Anh_KTBL_Buer.pdf

P-recovery in Berlin

Heinzmann and Engel (Berlin Wasserbetriebe BWB) presented a **detailed study of P-recovery feasibility at Berlin’s two largest sewage works** (Wassmannsdorf 169,000 m³/day and Ruhleben 208,000 m³/day) and a pilot experiment at WWTP Wassmannsdorf. These works achieve <0.5 mgP/l discharge by carefully designed and controlled biological P-removal only.

Material flow balances for phosphorus at both of these sewage works were carried out and showed very similar results: 5% of inflow P goes to filter sand, aerosols, etc, 11% to primary sludge, 81% to bio-P secondary sludge, and just 3% to discharge water.

Wassmannsdorf sewage treatment works has suffered major struvite incrustation problems in sludge centrifuges (see <http://www.nhm.ac.uk/mineralogy/phos/Nordwijkerhout/Heinzmann1704.doc>), so that P-removal for recovery offers significant potential advantages in terms of operating cost savings and problem prevention. Analysis of the material flow balance suggested that the optimal site for P-recovery would be at the outflow of the anaerobic sludge digesters.

A pilot struvite precipitation installation has therefore been installed, with an aeration reactor in which magnesium chloride is dosed (and aeration drives off carbon dioxide, resulting in a pH increase). This also enabled dosage of cationic flocculation agents (prior to the sludge centrifuges) to be reduced.

However, the struvite was then mixed in with digested sludge in the centrifuges. Analysis showed that 95% of the struvite crystals were of length >63µm. One hydrocyclone was therefore installed between the struvite reactor and the centrifuges in order to selectively recover the larger, denser struvite crystals but not the organic sludge. Trials

were also carried out with a recycling of the outflow of the hydrocyclone back to the precipitation reactor. The hydrocyclone separation resulted in a precipitation product, after washing, with 17% phosphate = 6.3% phosphorus (P) and a very low organic content, but with significant levels of other precipitation products. Impurity levels (heavy metals, AOX ...) were tested and found to be very low (lead, chromium, nickel, AOX < 100 ppm, copper and zinc < 300 ppm).

A full translation of this paper

(Heinzmann and Engel) is available at

<http://www.nhm.ac.uk/mineralogy/P-recovery/>

Phostrip and P-recovery

E. Kaschka, Posch & Partners Innsbrück Austria, <http://www.pap.co.at/english.html>, presented experience of integrating phosphorus recovery into the “Phostrip” biological nutrient removal process. This process is based on the inclusion of a phosphorus “stripper” in the return stream recycling sludge from the final settling tank back into the biological nutrient removal system. This stripper is an anaerobic (up to 14 hours) tank (plus pre-stripper tank), which ensures both thickening of the sludge and release from the sludge of biologically removed phosphorus (stored within bio-P micro-organisms cells) into a soluble form. The lowering of the micro-organism cellular P-content in the return sludge improves the efficiency of the biological phosphorus removal process.

The authors presented a detailed phosphorus flow balance for two municipal sewage works operating “Phostrip” process biological nutrient removal: Hoffkirchen Austria (6.3 kgP/day inflow) and Darmstadt-Eberstadt Germany (69kg P/day inflow). Both plants achieved over 90% P-removal. Phosphorus concentrations in the P-stripper outflow water were respectively 80-110 and 25-30 mgP/l, but with experience showing that concentrations at Darmstadt- Eberstadt could be increased by increasing the anaerobic residence time in the stripper. The authors conclude that the Phostrip system provides, in the P-stripper outflow, a cost-effective site for phosphorus recovery.

Experiments at Darmstadt-Eberstadt are reported (Hillenbrand *et al.* 1999) where lime slurry was added to the P-stripper supernatant outflow to precipitate calcium phosphates (pH raised to 9 –

9.5). After static settling, the product reached around 25% dry solid content, so that further dewatering (filter press) was necessary to achieve a produce with 40% dry solid with low organic content and 19-20% phosphorus which hardened to a cake (Barti 2003). This product was not considered to be of value for direct use as a fertiliser, because of the low solubility of the calcium phosphates, but had value as a soil improver, or as a raw material for the cement industry, or particularly as an additive in the calcium carbonate industry.

Phosphorus can also be recovered from the P-stripper outflow stream as calcium phosphate pellets using a fluidised bed reactor as at Geestmerambacht sewage works (see S. Gaastra’s papers at the First International Conference on P-recovery <http://www.nhm.ac.uk/mineralogy/phos/gaastr.htm>), or in theory by precipitation as aluminium phosphate or as magnesium ammonium phosphate (struvite = MAP).

Cost elements for Phostrip system operation at four different municipal sewage works in Austria were presented (Wallen, Schlalchen, Braunau, Hofkirchen). Estimated costs for P-removal by chemical precipitation (iron addition) were compared to those for biological P-removal (Phostrip) with either filtration or phosphorus recovery (as calcium phosphate cake). For all sludge handling/disposal cost scenarios (50€/tonne upwards), the biological P-removal options were cheaper than chemical P-removal plus polymer flocculation. Phosphorus recovery costs were comparable or marginally higher than Phostrip+filtration costs, depending on costs of filter materials.

A full translation of this paper (Kaskchka)

is available at

<http://www.nhm.ac.uk/mineralogy/P-recovery/>

A. Giesen and R. de Boer, DHV Amersfoort <http://www.dhv.com>, The Netherlands, presented experience in phosphorus recovery using the “Crystallactor” process. Plants using this fluidised bed precipitation process have been constructed and operated for removal/recovery of heavy metals, fluorides from industrial liquors, for the softening of drinking and process water, and for the recovery of phosphates from municipal sewage works liquors (see in particular S. Gaastra papers indicated above) and from food-industry waste waters (see P.

SCOPE NEWSLETTER

Piekema paper at the Second International Conference on P-Recovery (<http://www.nhm.ac.uk/mineralogy/phos/Nordwijkerhout/Piekema.pdf>). This process can produce compact pellets (0.8-1.0mm) with 90-98% phosphate content and low (1-5%) water content after simple draining. Experience at Westerbork and Geestmerambacht municipal sewage works, The Netherlands is summarised (calcium phosphate precipitation), as well as struvite (MAP) precipitation in a potato processing plant waste stream. In recent pilot plant experiments for a chemical industry waste stream, potassium magnesium phosphate precipitation was tested, but magnesium phosphate precipitation proved more effective. In ongoing tests reported with a food industry waste stream, calcium phosphate and magnesium phosphate precipitation are being compared (in all cases, using the Crystallactor process). The authors indicated that magnesium phosphate precipitation can be achieved under high loading and is not perturbed by carbonate concentrations (which are a problem for the Geestmerambacht sewage works calcium phosphate Crystallactor operation).

C. Cornel and D. Schaum, Technical University Darmstadt, Germany, presented various processes proposed for recovering phosphates from sewage sludge or from sewage sludge incineration ash. The Kemira Kemwater Krepro process is presented, including detailed mass balance and cost information (see SCOPE Newsletter n°41 page 32, <http://www.ceep-phosphates.org/scope/articles/scope41/Scope41.pdf>

The authors also briefly present the **Seaborne process** for recovering different values from organic sludge, for which a pilot plant is operational at Owschlag and a full-scale plant is being constructed at Stadt Plön (both Schleswig-Holstein) – see below, and the Aqua Reci (Feralco AB <http://www.feralco.com/feralco/ferintr1.nsf>) process for wet oxidation of sewage sludge. The authors indicated that sewage sludge incineration ash can contain 4-8% phosphorus (P) but that heavy metal or other contaminants can be an obstacle to the use of this as an industrial raw material. They conclude that under present conditions, phosphorus recovery by these routes is unlikely to be economically feasible.

N. Vesterager, Seaborne Environmental Research Laboratory GmbH, Owschlag, Germany, presented

the Seaborne process, which treats organic materials (such as sewage sludge) to produce biogas by fermentation (methane), heavy metal removal (by sulphide precipitation), and nitrogen and phosphate values as ammonium phosphate for fertiliser. The process can be adapted to recover magnesium or calcium phosphate.

D. Donnert, Karlsruhe Research Centre KZH, Germany, presented experimental phosphate precipitation from waste waters using Calcite and Tobermorite as seed materials. The interaction of phosphorus with the two materials led to fixation onto the seed material surface, and the precipitation of calcium phosphate with calcium from the Calcite improves the process for this material. The authors suggest that this process can be used to recover phosphates from waste waters with relatively low phosphorus concentrations in the range 5-10 mgP/l, as well as from liquors with higher concentrations (>200 mgP/l). Phosphorus precipitation is inhibited by the presence of organics in the water, particularly for the Calcite seed material. See also <http://www.nhm.ac.uk/mineralogy/P-recovery/projects.htm>

In a final paper, **Jürgen Hahn, of the German Federal Environment Office (Umweltbundesamt UBA)** announced the development of phosphorus recovery for recycling as an objective, suggesting that technical process R&D could be funded from existing taxes on waste waters. A translation of this paper is available at: <http://www.nhm.ac.uk/mineralogy/P-recovery/UBApressrelease.doc>

Phosphorus recycling

Phosphate removal

P-release in biological P-removal

Biological phosphorus removal processes (EBPR) in sewage treatment function through a series of anaerobic, anoxic and then aerated phases. In the presence of readily available fatty acids, micro-organisms subject to such conditions, take up significant levels of phosphates during the final aerobic phase, enabling high levels of P-removal to be achieved. However, if this phosphorus-enriched

EBPR sludge then becomes anaerobic, the micro-organisms will tend to re-release phosphorus, as soluble phosphates. This is an issue in sludge holding tanks, sludge thickening, and particularly in anaerobic sludge digestion.

The authors used a laboratory scale experimental anaerobic sludge digester (17 litre, 35°C, 20 day solid retention time) to assess **rates of and conditions for soluble phosphate release from EBPR sludge**. The sludge was generated by a 1.3m³ pilot EBPR plant fed with real sewage, and was thickened by centrifuge before digestion. The digester was fed with various combinations of EBPR sludge (from the biological P-removal part of the pilot plant), primary sludge from the pilot plant (from the primary settling tank, upstream of the EBPR part of the plant), pre-fermented primary sludge (after anaerobic treatment at 20°C for 6 days), and EBPR sludge from the pilot plant operated with additional phosphate in its influent (resulting in EBPR sludge with a higher P content).

Phosphate concentrations in the EBPR sludge reached 300g totalP/m³ and 400g when the pilot plant influent was dosed with additional phosphate (P/COD = 3-3.5% and 4-4.5% respectively). The P/COD ratio was reduced to 1.7-2% using the mixed primary + EBPR sludge (just over 50% primary sludge) and to 2-2.3% using mixed pre-fermented primary + EBPR sludge (similar ratio).

Modelling P-release

A mathematical model was developed of phosphorus release mechanisms under different sludge conditions, taking into account in particular effects of concentrations of iron, calcium, aluminium, magnesium ions on phosphate precipitation:

* **struvite (magnesium ammonium phosphate)** is precipitated according to the release of magnesium ions by hydrolysis of organic polyphosphates in the sludge and other degradation of organic solids. A ratio of 0.25 gMg/gP is frequently found.

* **calcium ions** largely originate in sludge from release from detergent zeolites (sodium aluminium silicates). These zeolites are used in detergents to sequester calcium ions from the wash water.

* **detergent zeolites** in the sludge also provide aluminium ions when they are partly degraded. Aluminium release was found to be constant in the

digester at 0.52%/day. Almost all aluminium in fresh sewage sludge is known to come from by detergent zeolites (Jardin and Pöpel 1994, Wild *et al.* 1996).

* **iron** is only available for fixation of phosphorus after deduction of that needed for available sulphur

The model allows prediction of phosphorus release rates at different plant operating conditions, for different process configurations, water hardness, concentrations of detergent zeolites, phosphorus, etc.

Return of phosphates to sewage works head

The authors found that 10-25% of phosphorus in EBPR sludge was released as soluble phosphate when EBPR sludge alone was digested, levels which would represent a considerable obstacle to efficient operation of biological phosphorus removal on return to the sewage works input. When mixed sludge was digested, however, even with pre-fermented primary sludge, release of soluble phosphates could be kept below 10% (equivalent to 20% of the EBPR sludge P-content, if it is assumed negligible release from the primary sludge).

This does not take into account the risk of return of insoluble phosphates to the sewage works head, which will also occur if the separation of solids from the digester supernatant is insufficient. If such insoluble phosphates are not easily soluble, they should not affect the biological P-removal process.

The authors note that a further problem area can be the thickening step prior to sludge digestion, as this can be long enough for anaerobic conditions to develop and phosphates to be released, but too short for these to be precipitated. This is particularly true if EBPR and primary sludges are mixed for thickening, because the available fatty acids in the primary sludge will accelerate phosphate release.

"Prediction of recycle phosphorus loads from anaerobic digestion" Wat. Res. Vol. 13, n°9, pages 2300-2308, 1997.

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Scaling

Preventing struvite precipitation

Struvite (magnesium ammonium phosphate = MAP) scale formation has been reported as causing problems in municipal waste water treatment works (wwtp), in severe cases obliging replacement of lengths of piping or affecting pumps, aerators, centrifuges. The hard deposits formed can often only be removed by chipping them away by hand, or by using corrosive acid to dissolve them, leading to significant operating costs.

Struvite precipitation particularly occurs where aeration causes CO₂ to be driven off, leading to a pH increase. Ohlinger (1999) showed that increased energy input to sludge liquors, creating turbulence, led to CO₂ off-gassing, increased pH, and so struvite precipitation.

Whilst struvite precipitation offers a potential route for recovering phosphorus from sewage for recycling (P-recovery), it is thus, on the other hand, often a significant operating problem.

Beaker tests using sludge liquor were used to assess the effectiveness of 4 commercial anti-scaling additives and of 3 chelating agents in preventing struvite precipitation. The most effective product (the chelating agent EDTA) was also tested to establish whether it could be used to dissolve away existing struvite deposits.

Anaerobically digested sludge liquor from the centrate line of **Colehill Sludge Destruction Plant, Warwickshire, England** (Severn Trent Water) was acidified to prevent struvite formation in storage or transport, then centrifuged to remove suspended solids. Phosphorus, calcium and magnesium concentrations were in the ranges 0.5 to 3 mMol. To test struvite precipitation, magnesium was added up to around 3mM/l, then the liquor was stirred for 5x8 hours at 150rpm using a stainless steel impeller with a surface of just over 12,000mm². After 8 hours of stirring, the liquor was replaced. Between each 8-hour run, the impeller was dried and weighed (to assess deposits). After the 5th and final 8-hour run the impeller was placed in nitric acid to dissolve the struvite deposit, and phosphorus, magnesium and calcium concentrations measured to

determine the total mass of struvite deposited. Each experiment was repeated in triplicate.

Effect of pH

The acidified liquor's starting pH was below 7, rising to 8.5 after 8 hours stirring. Struvite mainly precipitated on the points of the impeller most subject to turbulence. The mass of struvite deposit clearly increased, linearly, with each 8-hour run, with slightly higher masses of deposit at higher supersaturation ratios

Inefficient commercial products

The effects on struvite precipitation of 4 commercial anti-scaling agents, dosed at around 30 mg/l, and of 3 chelating agents (acetyl acetone = AcAc, NTA, EDTA), dosed at around 8mM/l, were compared to a control (no chemical addition).

Only one of the four anti-scaling products had any significant impact on struvite precipitation. This one product led to an approx. 50% reduction in struvite deposits, but further work would be needed to establish whether this could be achieved at dosages economic for real liquors. Of the chelating agents, AcAc had no discernible effect, NTA a limited effect, but EDTA was very effective (more effective than the one effective anti-scaling agent). The authors suggest that the effect of EDTA may be achieved by chelating magnesium ions out of solution, thus removing them from availability for struvite precipitation.

Further work was carried out using EDTA at different dosage concentrations, suggesting that a molar dosage of 2 EDTA : 1 magnesium was effective in controlling struvite precipitation (95% reduction). Surprisingly, EDTA, even at molar ratios <2:1, also proved able to cause significant dissolving of previously formed struvite deposits after 8 hours, with the dissolution rate being related to the EDTA concentration.

"Chemical control of struvite precipitation", Journal of Environmental Engineering, vol. 129, issue 5, May 2003, pages 419-426 <http://ojps.aip.org/eeo>

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SCOPE NEWSLETTER

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See also summaries of: "Struvite formation, control and recovery" and "Struvite formation and the fouling properties of different materials" in *Water Research*, see SCOPE Newsletter n°50 at www.ceep-phosphates.org

The Netherlands

Biological P-removal for sustainability

A combination of specific design of the mainstream biological nutrient removal configuration of municipal waste water treatment works, integrated with ammonium removal and phosphorus recovery from the return sidestream and sludge digestion (for methane production) enables overall environmental impact of sewage treatment to be minimised, in particular energy consumption, greenhouse gas emissions and phosphorus recovery for recycling.

The proposed biological nutrient removal system is based on the "BCFS[®]" (Biological and Chemical phosphorus and nitrogen removal system), developed from the standard UCT biological nutrient removal configuration. The implementation of this system in the upgrading of existing sewage works is described in [SCOPE Newsletter n°32](#) (Van Loosdrecht *et al.* 1998).

The standard configuration for biological nutrient removal plants is a mainstream series of anaerobic, anoxic then aerobic compartments, enabling respectively selection of phosphorus-accumulating micro-organisms, reduction of nitrates (to remove nitrogen), then phosphorus uptake by these organisms (in the presence of readily available organic carbons) in the anoxic (denitrifying dephosphatation) and aerobic zones. The BCFS configuration includes a "contact" zone between the anaerobic and anoxic zones, fed with nitrate-containing return sludge, to remove hydrolysis products and repress filamentous bacteria development; and a "mixed aeration" tank between the anoxic and aerobic zones. This mixed tank is aerated only if necessary and ensures simultaneous nitrification and denitrification to minimise effluent nitrogen levels. A sludge sidestream from the initial

anaerobic zone, rich in soluble phosphates, is used to enable phosphorus recovery for recycling.

This BCFS configuration selects denitrifying P-removal bacteria, which can use nitrate as an oxygen source instead of air in the aerobic P-removal zone, thus reducing by up to 50% the demand for readily available carbon necessary for nitrogen and phosphorus removal. The carbon thus economised is available for methane production in sludge digestion, thus providing net energy savings. Also, aeration energy requirements are reduced.

Struvite recovery

In order to optimise plant design for sustainability, whilst using known and tested technologies, the authors suggest that phosphorus recovery and ammonium removal should be installed downstream of the sludge digester (methane production) in the above configuration. Phosphorus recovery can be achieved using struvite precipitation (by magnesium addition), and ammonium removal using the CANON process ("Completely autotrophic N-removal over nitrite" - a biofilm reactor supporting simultaneous nitrification and ANAMMOX nitrogen removal).

Approximately 50% of the influent COD to the sludge digester is converted to methane, the rest remaining in sludge requiring disposal.

The inclusion of a pre-settling tank on the plant inflow allows the volume of the biological nutrient removal reactors to be reduced by around 50%.

The authors model inputs, outputs and operating parameters for an 8,500 m³/day inflow sewage treatment plant (inflow COD = 625 g/m³/day, TKN = 60 mgN/m³, P = 9.5 gP/m³). Effluent concentrations are 30 gCOD(inert)/m³, <5 - 9 gN/m³ and <0.5 - 0.6gP/m³. The model suggests that 28% of influent COD can be converted into methane via sludge digestion, and 49% of total plant inflow phosphorus can be recovered as struvite, almost without additional costs.

Greenhouse emissions

Net energy use and CO₂ emissions are significantly lower than for a conventional sewage works. Energy use for aeration is reduced by 35-44%. Also, increased COD retention in sludge transferred to digestion, allows an increase in methane production

of 154-271%. The net energy balance for the plant then becomes positive: more energy is produced in methane than is consumed in the treatment processes and operation.

The authors suggest that such integrated sewage treatment systems, optimised for sustainability, could be compared favourably to proposed separate urine collection and treatment systems.

“Contribution of P-bacteria in biological nutrient removal processes to overall effects on the environment”, *Water Science and Technology Vol. 44 No 1 pages 67-76, 2001* <http://www.iwaponline.com/wst/toc.htm>
X-D. Hao^{1,2}, J.J. Hiejnen², Y. Qian^{1,2}, M.C.M. van Loosdrecht².

“A proposed sustainable BNR plant with the emphasis on recovery of COD and phosphate”, *Water Science and Technology Vol. 48 No 1 pages 77-85, 2003*
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<http://www.iwaponline.com/wst/toc.htm>

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Nutrients and ecosystems

Sweden

Variations in benthic algae

Lake Erken in Sweden (59°50'N) is a 24 km², mean depth 9m, dimictic, alkaline and naturally slightly eutrophic lake with a mainly rocky or stony shoreline. Algae growing on submerged rocks floor,) were sampled by SCUBA diving.

Samples were collected on 9 dates in May-October 1996 and on four dates May-July 1997, in each case at several sites and a variety of depths: the sampling used different horizontal scales (cm, dm, 10m, km), compared both within and between seasons and successive years, and at depths of 0, 1 and 4 m. Samples were analysed for algal biomass/surface area, parameters such as nutrient:carbon ratios, and algal taxonomical composition. Over the same

periods water physico-chemical parameters were monitored in the pelagial, as well as parameters such as light and wind speed, and also specific samples of water were taken for nutrient analysis directly at the sampling sites.

Nutrient status of the collected algal samples was assessed on the basis of both nutrient:carbon ratios (C:N:P) and APA (alkaline phosphatase activity). Severe phosphate limitation was considered as corresponding to C:P > 369 and N:P > 32 on an atom:atom basis, or APA > 0.2 nmMUP_a/Chl_a/min; nitrogen limitation as C:N > 11. No nutrient limitation was assessed to correspond to C:N:P ratios of around 158:18:1.

Average (median) epilithon algal biomass for all sampling sites and periods was 8 µgChl_a/cm², 1580 µgC/cm² and 5 mm³/cm² biovolume. Average (median) nutrient ratios were C:N:P = 210:24:1, indicating an overall slight phosphorus limitation, but with high levels of variation both in space and time.

Patchiness

There was considerable horizontal variation in both algal biomass and nutrient status, with both small and large horizontal scales accounting for large variations. There was also considerable variation with depth (lowest biomass at 0m depth) and with time (within-season variation was very high, but there was an overall increase in biomass in the Autumn after a summer minimum). *“Patchiness in the nutrient status of algae was not coupled to the patchiness of biomass, indicating that internal nutrients and biomass were regulated by different factors”*.

Local variation of nutrient ratios was much less than for biomass, suggesting that herbivore grazing could be an important factor in the biomass variability. Epilithon algae were obviously not nutrient regulated over the whole lake in the same way at the same time: at one site, algae seemed to have adequate supplies of both nitrogen and phosphorus; at other sites there were nutrient limit spots occurring only centimetres away from spots without apparent limitation. Nitrogen and phosphorus limitation appeared to occur independently of each other. Contrary to expectation, algae growing near local sources of nutrients (residential areas, bird roosts) did not show high nitrogen or phosphorus levels.

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The authors conclude that “*variation in algal nutrient status was not coupled to that in algal biomass, indicating that different factors were responsible. Neither could we detect direct control of biomass by internal nutrients ... their effects may be overridden by biomass removal, turbulence or grazing*”.

This shows the importance of sampling design in such studies, in order to limit the inaccuracies resulting from the wide variations, including over distances of 10cm, of algal biomass and nutrient status. Wind and water currents (including wave

effects), light limitation and groundwater effects are identified as key factors requiring further investigation.

“*Spatial and temporal variation in the biomass and nutrient status of epilithic algae in Lake Erken, Sweden*”.

Freshwater Biology, n°47, pages 1191-1215, 2002.
<http://www.blackwellpublishing.com/journals/fwb/> and
<http://www.blackwell-synergy.com>

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