

Conference Summary

Second International Conference on the recovery of phosphorus from sewage and animal wastes

**Noordwijkerhout, The Netherlands
12 & 13 March 2001**





Recycled phosphates recovered from sewage and ready for industrial use (magnified)

The Conference CD including papers and slides presented and other background documents is available on request from :

CEEP (Comité Européen d'Etudes des Polyphosphates)

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Papers are also available at the phosphate recovery and recycling website managed by Natural History Museum, London :

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

Conference jointly organised by :



EUROPEAN CHEMICAL INDUSTRY COUNCIL

(European Chemical Industry Council)

CEEP

Centre Européen d'Etudes des Polyphosphates

(the European phosphate industry's joint research association, a CEFIC Sector Group)



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Note concerning references :

“CD” indicates that the cited paper is included on the **Conference CD** (available on request from cja@cefic.be) and at the Natural History Museum London’s P-recovery web site <http://www.nhm.ac.uk/mineralogy/P-recovery>

“SCOPE” indicates that the cited paper is summarised in the “SCOPE Newsletter” in an issue included on the Conference CD and also available at www.ceep-phosphates.org

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1. Introduction

Over 260 representatives of the water treatment industry, regulators and scientists were present at the Second International Conference on P-recovery in Nooordijkerhout, The Netherlands, March 2001. Social and economic perspectives, and the state of technical development of processes, for the recovery of phosphates for recycling from sewage and animal wastes were presented and discussed.

This Second International Conference on this subject took place three years after the first such meeting at Warwick University, UK, in May 1998. The first Conference had been very much an exploratory meeting, bringing together actors from different areas of activity (water industry, research scientists, phosphate industry ...) to exchange very new ideas about the possibility of P-recycling. This Second Conference, however, showed a significant change of status of the question, with presentations of full-scale pilot trials now underway and discussions of the economic and industrial feasibility and deciding factors.

Overall conference conclusions

The Conference concluded that phosphate recycling is now desirable and technically feasible, as shown by the handful of plants already operational across the world and by the recent launch of new projects by water companies. There is a considerable practical interest in P-recovery from both water companies and regulators, in a number of countries.

The practical development of P-recovery, however, clearly depends strongly on local factors such as sewage works configuration, sludge management options, local markets for recovered phosphates, regulatory pressures. **The Conference identified four main drivers for P-recovery :**

- **improvement of sludge management (reduction of sludge production, facilitated disposal, optimised agricultural re-use)**

- **sustainable development and recycling policy**
- **improvement of biological nutrient removal process performance**
- **resale of recovered phosphates**

A prerequisite for P-recovery is of course the implementation of P-removal, but this is expected to concern most medium-large sewage works (implementation of the EU Waste Water Treatment Directive). In the short-medium term, **P-recovery is most likely to develop in sewage works operating biological nutrient removal**, because these plants offer liquid supernatant streams suitable for the precipitation of recyclable calcium phosphates, struvite¹ or aluminium phosphates. Other P-recovery pathways may also develop in response to specific local circumstances (eg. where sewage sludges are used in cement works, for which phosphate content is a problem) or in response to new technologies which enable application in other sewage works configurations (ion exchange, membranes, new biological processes ...)

There is also a huge potential for P-recovery from animal manures, but this will not develop until regulators enforce nutrient discharge constraints on agricultural operators. Various waste streams from industries (food industries, metal treatment, micro-electronics ...) have high soluble phosphate concentrations, and P-recovery can be attractive in these cases.

From theory to practice

This Second Conference included presentations of trial full-scale P-recovery plants now being operated or developed in a number of countries. Eight of these are summarised below.

These different operating experiences **convincingly demonstrate that P-recovery is technically possible** in full-scale operations in sewage works, with phosphates being recovered in various forms. They also however open a number of questions regarding the economic and other driving conditions in which such P-recovery processes

¹ Struvite is magnesium ammonium phosphate $MgNH_4PO_4 \cdot 6H_2O$, sometimes referred to as "MAP". Care should be taken, however, as in agronomic literature MAP is generally used to refer to Mono Ammonium Phosphate fertiliser.

could become sustainable, the routes for recycling the recovered product, and scientific perspectives for optimising recovery process operation.

As well as addressing these issues, however, the Conference also discussed the basic question of “what is P-recovery?”, and why is there a demand to develop processes to recover phosphates from sewage in a chemical form rather than simply transferring them into sewage sludges.

2. Why “recover” phosphates from sewage ?

EU environmental legislation and/or local environmental objectives require phosphates to be “removed” from sewage, and increasingly from effluents from animal production units, wherever these discharge into “sensitive areas”. The relevant EU legislation is the Urban Waste Water Treatment Directive 91/271 and the Water Framework Directive 2000/60.

The application of these policies means that phosphates (be their origin human, animal, industrial or detergents) are **transferred into sewage sludges or collected animal manures**. The Institute for European Environmental Policy² estimated that the full application of Directive 91/271 will result in a total of around 220-240,000 tonnes per year (P) of phosphates being transferred into sewage sludges. Around 2 million tonnes per year (P) of phosphates are also present in agricultural manures in Europe.

Some 53% of sewage sludge in Europe (EU Commission COM(98)775) and a large majority of agricultural wastes are currently spread on agricultural land. In this case, the phosphates present in these wastes are effectively recycled, as they are returned to the soil as fertiliser. However, there is increasing pressure on agricultural sludge spreading (see conference discussion below), so that in many cases this “natural” route for phosphate recycling is being closed.

“P-recovery” therefore refers to processes whereby the phosphates can be recovered from

sewage and animal wastes in a form which can be used in either industrial phosphate processes or in fertiliser production, rather than being transferred into sludges.

Four driving forces for P-recovery

Where “P-removal” from sewage is required and where agricultural re-use of sludges is under pressure (either no longer locally possible, or where the field area available for spreading is being reduced), the Conference identified four drivers for “P-recovery” :

- **improvement of sewage sludge management (cost, environmental impact ...)**

P-recovery can **reduce the quantity of sewage sludge** generated by sewage works operating P-removal, and can also improve sludge management by **reducing the phosphate content of the sludge** produced. These aspects are detailed below. P-recovery will **significantly improve the characteristics of sludge as regards thermal treatment** (incineration ...) or use in cement factories. These aspects are addressed in the papers by Paul, Evans and Jeanmaire (CD) and were largely discussed at the Conference.

- **sustainable development**

Phosphates are a non renewable, and non replaceable resource (as the element phosphorus is essential for all life processes), although reserves exploitable at current technical and economic conditions are estimated to be over a cen-



Nina Sweet situates P-recovery in the UK Environment Agency's strategy.

² European Environmental Agency unpublished data given in “The role of the 1991 EU Urban Waste Water Treatment Directive in reducing phosphorus discharges in France and Spain”, Farmer A. et al., European Water Management vol.3 n°4 Aug. 2000 – see SCOPE 34

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ture (twice those of oil) with large reserves of low-grade rock also existing. For this reason, good environmental stewardship suggests that phosphates should be recovered from waste streams for recycling.

One country which has adopted such a policy is **Sweden³ where a national target of recovering and recycling 75% of phosphates from sewage has been discussed.** For information : this has been confirmed by a Government Decision of 11/4/2001 asking the Swedish National Environment Protection Agency to draw up an “action programme with the aim of achieving a practical and achievable scale of recycling of phosphorus contained in sewage sludge”. In order to move towards achieving this target, Sweden now generally requires P-recovery to be installed as one condition for authorisation for sewage sludge incineration plants. The cities of Ekilstuna, Falun, Halmstad, Malmö, Södertälje and Stockholm are already subject to such a requirement, or the issue is now being addressed.

Nina Sweet of the UK Environment Agency indicated that their strategy “includes a specific action to work with others to promote the development and uptake of P recovery and recycling technologies and practice within the UK”.

- **improvement of biological nutrient removal operation**

P-recovery can improve biological phosphorus removal efficiency and reliability by reducing the levels of soluble phosphate being returned to the sewage works head in sludge treatment supernatants (filtrate ...) and by contributing to **resolving deposit problems** in piping and other components (pumps, filter belts ...). These deposit problems are often related to combinations of high soluble phosphate, ammonium and carbonate concentrations (the latter resulting in pH increases when de-gassing occurs), and tend particularly to occur in sludge digestion or dewatering lines.

- **resale of recovered phosphates**

The market value of recovered phosphates will depend on the chemical form in which they are recovered, on the quality of the recovered

product, and on local market conditions. Unitika Ltd obtain a price of 250 €/tonne for sewage-recovered struvite in Japan⁴, but estimates by different authors at the Conference for market values in Europe varied significantly (see below). One question on which there remains discussion is the fertiliser value of struvite and of different forms of iron phosphate. A significant volume of literature and field experience suggests that **struvite certainly can be used by the fertiliser industry and is a good fertiliser for direct application⁵.** Pot trials of struvite in European soil conditions were one outcome of the Conference (joint funding by CEEP and several water companies present at the Conference) and are currently underway. These should provide basic fertiliser value results for struvite under modern recognised agronomic science conditions.

The obligation of “P-removal” from sewage is thus not in itself a driver for P-recovery, but it is a prerequisite. If P-removal from sewage is not required, then P-recovery is most unlikely to be considered - but some 56-62% of all phosphates in European sewage will need to be removed once Directive 91/271 is fully applied : P-removal can be achieved using know technologies, either chemical or biological processes. The application of these processes may result in situations where the above driving forces for P-recovery do apply.

3. Field experience of P-recovery presented at the Conference

Full-scale struvite crystallisation unit in the sludge dewatering supernatant line of the Treviso Biological nutrient removal sewage works, Italy.

Paolo Battistoni et al., Ancona University, Italy

This P-recovery reactor uses air stripping to precipitate phosphates and is currently at the initial testing phase. Whilst the P-recovery unit is now operational, the plant’s new biological phosphorus removal installations are not yet stabilised, so that the supernatants reaching the P-recovery reactor do not offer the characteristics for which it was designed to operate. The unit is therefore

³ CD paper Wallgren • ⁴ CD paper Ueno • ⁵ See for example CD report Liberti ch.6, Scope 43 page 3, Scope42 page 13 • ⁶ European Environmental Agency unpublished data given in “The role of the 1991 EU Urban Waste Water Treatment Directive in reducing phosphorus discharges in France and Spain”, Farmer A. et al., European Water Management vol.3 n°4 Aug. 2000 – see SCOPE 34

Recovery of phosphorus from

currently being tested with artificially dosed waste-waters. The P-recovery unit and preliminary performance results were presented in the paper to the conference⁷ : 55 to 64 % of inflow phosphates are precipitated onto the granules for recovery, along with some precipitation of calcite (calcium carbonate). Better results and less calcite formation are expected to be obtained once the sewage work's biological P-removal becomes operational as this will increase the soluble phosphate concentration and the pH in the unit's inflow.



*Yasanori Ueno,
Unitika Ltd, Japan,
presents commercial
operating experience
of 3 struvite recovery
plants*

Full-scale struvite recovery units at Shimane Prefecture sewage works, Japan
Yasanori Ueno, Unitika Ltd., Japan

Three P-recovery units are currently operational at this sewage works, two of which have been in place since 1998 (500 m³/day and 150 m³/day) and one since 2000 (500 m³/day). These units treat the filter supernatant from the sludge treatment process (anaerobic digestion) of the 45000 m³/day biological nutrient removal sewage works. Magnesium hydroxide and sodium hydroxide are added to bring the Mg/P ratio to 1 and to increase pH so that struvite (= magnesium ammonium phosphate MAP) is precipitated as pellets in a fluidised bed reactor. The process was installed because the soluble phosphate in the sludge treatment supernatants being returned to the head of the sewage works were around 70% of works phosphate inflow, preventing effective biological P-removal, and the prevention of this by iron addition was generating considerable excess sludge with high disposal costs. The P-recovery units currently achieve 90% soluble phosphorus removal, enabling the work's biological P-removal process to effectively achieve P-discharge

standards, whilst producing 500 to 550 kg/day of 0.5 – 1 mm diameter granules of recovered phosphates as struvite which is sold to fertiliser companies for 250 €/ton, (transport costs covered by purchasers)⁸.

Calcium phosphate recovery in the full-scale Crystallactor® reactor at Geestmerambacht, The Netherlands

Pieter Piekema, DHV Water BV, and Simon Gaastra, Waterboard Uitwaterende Sluizen in Hollands Noorderkwartier water company, The Netherlands

The Crystallactor® process is a fluidised bed reactor precipitating calcium phosphates as recyclable pellets by the addition of calcium hydroxide. **Full-scale Crystallactor® units have been operated at three sites in The Netherlands (two sewage works, one food industry factory), the first being commissioned in 1988. The Conference participants were able to visit the full-scale Crystallactor® P-recovery installation, commissioned in 1993 and still operational, at the Geestmerambacht sewage works**, treating a soluble-P-rich sidestream of the biological P-removal process. This experience was presented by Simon Gaastra, who confirmed results already presented after four years of operation at the first Conference in Warwick (1998)⁹. This process currently requires the removal of carbonates from the liquors treated in the unit (by taking the pH down to around 6), which renders the process economi-



*The full-scale calcium phosphate recovery installation at Geestmerambacht sewage works, The Netherlands, was visited by Conference participants.
Photo : DHV, Amersfoort,*

⁷ CD paper Battistoni, but also Scope 39 page 12, Scope 41 page 20 and Wat. Res. Vol. 35 n°9 2001, pages 2167-2178

⁸ See also Scope 39 page 14 • ⁹ Gaastra paper from the 1998 Conference on CD

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cally and environmentally unattractive (chemical use), as the pH then has to be taken up to around 8 – 8.5 to achieve phosphate precipitation in the reactor. Avoidance of this decarbonation step through a better understanding of calcite / calcium carbonate precipitation interactions is clearly an essential requirement for the design of a viable process for recovering phosphates as calcium phosphates. The calcium phosphates recovered at Geestmerambacht do however offer good handling properties and around 11% phosphorus content, and are currently transported to the Thermphos factory at Vlissingen, The Netherlands, where they are recycled into industrial phosphate production.

Struvite recovery using seawater as a magnesium source

Yoshiharu Nawamura, Nishihara Corporation Ltd, Japan

Operating experience from 7 – 58 m³/day pilot fluidised bed struvite precipitation reactor at Hiagari Sewage Treatment Plant in Kitakyushu City, Japan, was presented¹⁰. The reactor treated liquors from sludge dewatering. Around 70% precipitation of dissolved phosphates was achieved in the reactor using aeration of 130 m³/m²/h, without chemical addition (influent pH 7.65), and higher P-precipitation efficiencies were obtained by using addition of sodium hydroxide to increase pH.

Pilot plant recovering iron phosphate from sewage at Helsingborg, Sweden

Ingmar Karlsson, Kemira Kemi Kemwater, Sweden

The **Krepro® process** uses a hot acid process to convert sludges (from sewage works using iron precipitation for P-removal) into a relatively dry bio-fuel (organic fraction) and recovers phosphates as **iron phosphates**¹¹. The iron phosphates recovered, ferric phosphates, contain around 10%P (phosphorus), and are presented as being plant-available for use as a fertiliser. The ferric phosphate produced in the Krepro® process is not water soluble but is ammonium citrate soluble. There was however some discussion at the conference as to the plant availability (and so value as a

fertiliser) of iron phosphates (see below). This is clearly an area where further work is required to establish clear indications as to the fertiliser value of iron phosphates in different forms, in raw and treated sludges from sewage works using iron precipitation P-removal processes.

Struvite precipitation reactor at Osaka, Japan

Fumio Mishina, Japan Institute of Wastewater Engineering Technology, and Satoru Ishiduka, Kurita Water Industries, Japan

A 5.3m high, **133 m³/day fluidised bed struvite precipitation plant** was tested at the Osaka-Minami ACE area-wide sewage treatment works, Southern Osaka. pH was adjusted to around 8.8 using sodium hydroxide, and liquid effluents from the sewage works sludge incineration unit's gas scrubber effluent was used as a magnesium source, achieving up to 50% P-recovery in the reactor. Magnesium chloride was also tested as a magnesium source in order to avoid effects of suspended solids in the gas scrubber effluent, enabling P-recovery to increase to 62%.

Pilot struvite precipitation reactor at Slough Sewage Works, UK

Yasmin Jaffer, Terri-Ann Clark, Pete A. Pearce and Simon A. Parsons

This sewage works operates biological phosphorus removal and is subject to ongoing and significant struvite deposit problems in the sewage sludge filter process and in the pipes carrying the filtrate from this process¹². Thames Water therefore wishes to install a phosphorus recovery process in order to pre-empt these deposit problems and to also reduce the concentrations of soluble phosphates being returned from the sludge filter process to the inflow of the works, in order to improve the biological P-removal. A lab-scale struvite precipitation reactor has been tested with success¹³. **A full-scale reactor is now under construction**, which will treat around one quarter of the sludge filtrate stream. This reactor is designed to be a stirred reactor, with the stirring being achieved by aeration. Magnesium hydroxide will initially be used to provide both magnesium and pH increase for struvite precipitation.

¹⁰ See also Scope 39 page 15 • ¹¹ Scope 41 • ¹² Williams paper from First P-Recovery 1998 conference on CD • ¹³ Scope 41 page 6

Pilot struvite precipitation at Oxley Creek sewage works, Brisbane Water, Australia

Elizabeth Von Münch, A. Benesovsky-Scott, J. Josey and Keith Barr

A 143 litre (20 – 120 litre/hour) **pilot fluidised bed struvite precipitation reactor** has been tested with success by Brisbane Water, Australia¹⁴. This pilot showed that 94% precipitation of inflow soluble phosphate could be achieved at a pH of around 8.5 (addition of magnesium hydroxide). The authors presented at the Conference a business plan for the application of this process to pig farm liquid wastes. The authors suggest that the recovered struvite should achieve a market price as a fertiliser of at least 300 €/tonne and that the process could be attractive for over 100 pig farms (300,000 sows) and around 20 municipal sewage works in Australia.

4. Sewage sludge management perspectives

4.1 *What future for the recycling of phosphates through agricultural spreading of sewage sludges ?*

There was considerable discussion at the Conference concerning both the future of agricultural spreading of sewage sludges, and the possible fertiliser value of iron phosphates present in sludges (or indeed of iron phosphates recovered as a pure product, for example by the Krepro® process).

The situation as regards agricultural spreading of sewage sludges varies considerably between different European countries. This is still a major route for sludge disposal in the UK, France, Spain ... whereas it has more or less completely disappeared as an option, or is expected to do so, in The Netherlands, Sweden ...

There was general agreement in discussion at the Conference that, **where logistically possible, agricultural reuse of sewage sludges is not only the cheapest disposal route, but also clearly the environmentally optimal option** – allowing

effective recycling of organic matter, nutrients and micro-nutrients contained in human and food wastes back onto farmland. However, in reality, there are many obstacles to agricultural reuse of sewage sludges : logistic (transport distances to sufficient areas of farmland around large cities), environmental (progressive contamination of farmland by heavy metals and other pollutants currently found in sewage sludges) and real or subjective fears about possible contamination by pathogens, prions, drugs, hormones, persistent chemicals or other molecules susceptible to be found in sewage sludges. This has led regulators to limit the spreading frequency of sewage sludges on agricultural land : eg the proposed tightening of the EU “sludge Directive” 86/278 by Commission Working Document ENV.E.3/LM¹⁵, the objective of which is to try to regain public confidence in sludge spreading by guaranteeing “safe” levels of contamination. At the same time, **farmers are increasingly refusing to accept sludge spreading on their land** (often under pressure from supermarkets’ product purchasing policies). All this is in a context where the implementation of EU requirements for sewage treatment are expected to double the quantities of sewage sludge being generated over the coming decade¹⁶.

Sweden’s farmers organisations for example, have recommended the country’s farmers to no longer accept sewage sludges on their land¹⁷.

Although agricultural spreading is thus the optimal recycling path for phosphates and other components of sewage sludges, there is thus every reason to expect this route to increasingly become unavailable, or to be very limited, for the sludge production of many sewage works, in particular larger works in or near urban areas where the area of fields nearby is proportionally small.

4.2 *P-recovery and sewage sludge management*

The recovery of phosphates in sewage works means that a significant part of the phosphates in influent wastewaters is transferred into a saleable recycled phosphate product, instead of into sewage sludge. This will both reduce the

¹⁴ Scope 41 and Wat. Res., 35, 151-159, 2001 • ¹⁵ Scope 37 page 2 • ¹⁶ Scope 31 page 9 • ¹⁷ Scope 36, page 2

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quantities of sludge being produced and modify its characteristics (lower phosphate content, and so lower P/N ratio).

Landfill of untreated sludge is now no longer an option in Europe (EU Directive 1999/31), and sea dumping of sludge has also been stopped (EU Directive 91/271), so that sludge treatment and disposal is now the highest operating cost factor for many sewage works. Where P-recovery can improve sludge management or reduce sludge/incineration ash production, it can therefore have significant positive environmental and economic implications.

Since the first P-Recovery Conference in Warwick, UK, 1998, further studies have been made of these questions, and these were presented at this second Conference¹⁸.

Nicolas Jeanmaire (Office Internationale de l'Eau) presented work aimed at producing a full evaluation of current knowledge of how P-recovery would effect sewage sludge production and management. This was based on a literature study, application of a water industry mass-balance model for sewage works operation, and interviews of a number of operational and research experts in this area across Europe. **Jeanmaire concludes that P-recovery will result in a small reduction in sludge production, for example of 3 – 3.8% of dry solids** for 75% P-recovery with typical sewage works characteristics, but that this reduction will not be “visible” to sewage works operators within the overall variations in sewage sludge production. This is significantly lower than the figures suggested on the basis of modelling work by Woods et al. at the First P-Recovery Conference (paper published in *Environmental Technology* July 1999, vol. 20, n°7, 663-680). Woods et al. compared “biological nutrient removal with P-recovery” to “chemical P-removal without P-recovery, whereas Jeanmaire considers only the comparison of “biological nutrient removal with” to “biological nutrient removal without P-recovery”. This is because he concludes that **it is in biological nutrient removal sewage works that current P-recovery technologies are susceptible to be technically operational.**

Where sludge is composted, on the other hand, phosphates can be retained in the compost and add to the products agronomic and so market value.

Etienne Paul (INSA Toulouse, France) presented work aimed at assessing the quantities of (additional) sewage sludge resulting from P-removal (not P-recovery) processes, and the disposal costs of this additional sludge (for France). The figure will depend not only on the population connected to sewage works operating P-removal, but also very directly on the P-removal processes being used (chemical P-stripping, biological nutrient removal, combined processes). For 15.3 million inhabitants expected to be connected to sewage works operating P-removal in France (after application of EU Directive 91/271), he estimates a sludge production resulting from P-removal processes of 40 900 T dry solids/year (4.5 % of the annual sludge production from urban wastewater in France, or **around 14% of sludge production related to this population**).

Paul estimates the economic cost of P-removal chemicals and sludge disposal for P-removal at around 15 M €/year for France, so that the 3 – 3.8% economy in sludge production estimated by Jeanmaire would equate to a **cost saving resulting from P-recovery of 450 – 570 000 €/year for France.**

As Jeanmaire emphasises, **the proportional reduction in the production of ashes, wherever sewage sludge is incinerated (or subject to other thermal treatment) will be significantly higher : between 12 and 48%**. This implies significant savings for the disposal of sludge incineration ash, for which landfill costs vary between 152 and 304 €/t.

Jeanmaire also indicates that P-recovery resolves the obstacle to the use of sewage sludges in cement factories which results from the fact that phosphate lowers the resistance properties of cements. Consequently, approximately 1% P/dry solids is an upper limit for sludge reuse in cement factories. P-recovery can enable this limit to be achieved.

The N/P ratio in sewage sludges exceeds the ratio for crop needs, and phosphates added to

¹⁸ CD papers Jeanmaire, Paul, Evans and Gaterell

agricultural soils will tend to accumulate (which is not the case for nitrogen). Furthermore, many European agricultural soils already contain relatively high levels of phosphates as a consequence of ongoing fertiliser use over the past fifty years. The result is that where heavy metals and other contaminants are kept to acceptable levels (which can be possible if industrial pollutants are separated and not discharged into municipal sewers), **phosphates are likely to be or to become the limiting factor for the agricultural spreading of sewage sludges** (eg. Marks quoted by Jeanmaire).

Tim Evans (environmental consultant) therefore looked at the implications of P-recovery in



Tim Evans, environmental consultant, suggested that the improved P:N ratio in biosolids resulting from P-recovery could give an annual cost saving (reduced transport distances for agricultural reuse) of 740,000 €/year for the UK

terms of agricultural spreading of sludges. He modelled field surface availability around sewage works and UK agricultural soil phosphate status (from available data), in order to calculate average sludge transport distance changes susceptible to result from a reduction in sludge phosphate levels due to P-recovery.

Taking a scenario of 200 medium-large sewage works installing P-recovery in the UK, **the total annual saving resulting from a reduction in average sludge transport distances to fields would be 740 000 €/year.** This equates to 165 €/tonne of P recovered - around half the market price of imported, mined phosphate rock at port of entry to the UK quoted by Gaterell et al.

5. Technical perspectives for P-recovery

5.1 Can phosphates be recycled as iron phosphates ?

Iron phosphates are found both in sewage sludge from sewage works using iron salts for chemical P-removal, and as a product of the Krepro® and other sludge treatment process (see above). There was discussion at the Conference as to the value of iron phosphates, in these different forms, as a fertiliser.

Fiona Hogan (UK W.S. Atkins – Anglian Water joint research project underway) presented intermediate results from an 8 month study of sewage sludges utilising six sludge-cake samples mixed with three main soil types (clay [high pH], sandy [low and high pH]). The samples included sludge cakes from sewage works operating or not P-removal (using iron salts) and after different treatments (stabilising, thermal drying ...). Different solubility fractions of the sludge cake phosphorus were assessed both initially and over time after mixing with soil and storage (both at 25°C in aerobic conditions, and in pots outside). Phosphates in leachate were also measured. It so far appears from this work that the use of iron salts for P removal increases the P content of the sludge (as would be expected) - but also that **the phosphates in these iron-treated sludges can become significantly bioavailable.** This is probably due to the iron phosphates reacting with the soil to form iron hydroxides. This effect was greater in clay versus sandy soils. P was found, however, to be less available from thermally stabilised sludges. This confirms work by other authors which suggests that soil type, water content and soil water mobility, as well as soil nitrogen metabolism are key factors in defining the actual plant availability of land-spread sewage sludges.

Elisabeth Kvarnstrom (Sweden, Lulea University of Technology) presented results of short (5 week) ryegrass pot-trial fertiliser value studies of the sludge-recovered iron phosphate product (10% P) from the thermal Krepro® process (see above).



Crystal of struvite precipitated from sludge liquors (Doyle et al, 2000)

The experimental method utilised a soil which was already rich in phosphorus, and a radioactive labelling method to assess whether plant P uptake was from soil or from an added P-product (recovered Krepro® iron phosphate or commercial water-soluble fertiliser) : radioactive phosphate was added to the soil before the start of the experiment whereas the iron phosphate and fertiliser phosphate used in the experiment were not radioactive. The author suggested that the results indicated that the recovered iron phosphate was 100% available in the soil system and could be considered equivalent to a good commercial (low N) fertiliser. However, it appears that the increase in plant growth and plant P uptake during the experiment were not higher with the recovered iron phosphate product (compared to the no added P control), whereas the commercial fertiliser increased both. The difference between the conclusions drawn from the radioactive P-ratio data and the yield and P-uptake data could be due to various factors including (i) the pot experiment was very short, (ii) the radioactive P-level of the soil (used to calculate the P uptake ratio) was determined soon after addition of the radioactive P to the soil, ie the added P and the labile pool were perhaps not in equilibrium, (iii) the soil used in the pot experiment was high in P so that a benefit from the phosphate products could not be clearly measured.

More work is clearly necessary to assess, and to understand the mechanisms of plant phosphorus availability of iron phosphates of different forms, in different soil types and soil metabolism contexts.

Jan Suschka (Poland, Technical University of Lodz) presented some initial tests which show that the biological conversion of iron phosphate to soluble phosphates is possible, by sulphate reducing bacteria to under anaerobic conditions. The biological reaction was very much COD/S ratio dependant, with higher initial sulphate concentrations yielding higher rates of P removal. This work shows that the biological extraction of phosphates from iron sludges is possible, and further work is now necessary to assess to what extent the process can be optimised (eg. by progressive selection of efficient bacteria and definition of optimal conditions).

5.2 Perspectives for P-recovery from sewage works operating biological P-removal

As presented above, the Conference heard presentations of a number of full-scale or pilot P-recovery installations now operational in sewage works across the world. In each of these cases, the sewage works is operating biological phosphorus removal. Jeanmaire, assessing the technical feasibility of P-recovery, concluded : “after two months of investigations throughout Europe on the subject, we believe that phosphorus can technically be recovered from municipal waste water treatment plants”. However, Jeanmaire also concludes that **P-recovery in sewage works is only feasible with currently available technologies in the case of activated sludge type plants equipped with biological P-removal**, and where these plants have both an anaerobic area (where the biologically assimilated phosphorus will be released from sludge) and then a phase where the P-rich supernatant is separated from suspended solids. This P-rich supernatant provides an appropriate feed stream for a P-recovery reactor functioning by precipitation or crystallisation (of struvite, calcium phosphates or aluminium phosphates).

This confirms the conclusions of work carried out for **STOWA, The Netherlands** and presented by Ferdinand Kiestra (Haskoning Consultant, The Netherlands) which suggests that **the main opportunity for the development of P-recovery**

in this country in the short-medium term is by phosphate precipitation processes operating in sewage works using biological nutrient removal.

Although this limits P-recovery feasibility (using currently developed precipitation processes) to certain sewage works types and configurations, it is compatible with widespread development of P-recovery across Europe. Biological P-removal is expected to develop significantly across Europe over coming years, because - although investment costs are higher and closer operating control is required - it offers the advantages of avoiding chemical purchase costs and significantly lower sludge generation, as compared to chemical P-removal¹⁹. Also, biological P-removal avoids possible difficulties resulting from the implementation of discharge consents for iron or aluminium, which may become difficult to meet for plants operating chemical P-removal. The installation of biological P-removal also enables nitrogen removal in the same installations, which is increasingly required in discharge consents. Biological P-removal is more likely to be installed in medium and large sewage works, which is where P-recovery is likely to be economically and logistically feasible.

Bram Klapwijk (Wageningen University, The Netherlands) et al. indicated that **around one quarter of municipal sewage works in The Netherlands are already operating biological P-removal**, concluding that with realistic P-recovery rate estimates, some 8,000 tonnes P/year could be recovered from these sewage works.

Frank Brandse (Waterboard Reest en Wieden, The Netherlands) and Mark van Loosdrecht (Delft University of Technology, The Netherlands presented) the BCFS® biological nutrient removal system²⁰ which enables **over 90% N and P removal**. They emphasised that this process offers liquid streams within the process with high soluble phosphate concentrations, suitable for the application of P-recovery by phosphate precipitation.

Wherever biological P-removal is operational, the sludge will tend to release back soluble phosphate wherever it becomes anaerobic. This is susceptible to occur where biological P-removal is



Jacques Leenen of STOWA (The Netherlands water industry research organisation) : biological P-removal offers opportunities for P-recovery

combined with anaerobic sludge digestion, but can also occur in the sludge dewatering line, for example in filter press or centrifuge units.

Andrew Wheatley et al (Loughborough University, Birmingham University, Severn Trent Water, UK). presented work concerning the behaviour of phosphates and other ions during the digestion of sewage sludges. Phosphorus is precipitated as ferrous phosphate in sludge digesters where iron has been used for chemical P-removal, whereas in digesters fed with sludge from biological nutrient removal sewage works, calcium is the major phosphate sink. In the latter case, soluble phosphate, magnesium and potassium are released within the digester. Phosphate and magnesium are rapidly re-precipitated but the potassium remains in solution.

Norbert Jardin (Ruhrverband, Germany) et al also presented work concerning the metabolism and chemistry of phosphates in the sludge from biological nutrient removal sewage works. **They indicate that such sludge can contain up to 7%P, with levels being correlated to those of magnesium and potassium** (this is expected, because these elements are involved in the production of organic polyphosphates in the biological P-removal process). 50 – 70% of the phosphorus in the sludge was estimated to be as organic polyphosphates. Stabilising the sludge from the biological nutrient removal sewage works results in a near complete hydrolysis of polyphosphates. As a result, phosphate, magnesium and potassium are released.

¹⁹ CD paper Paul • ²⁰ CD paper Brandse, and also Scope 32 page 8

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However, only potassium remains in solution whereas magnesium and a part of the released phosphate are precipitated as struvite and another large fraction of the released phosphate is fixed by adsorption to aluminium solids.

Thus, a careful study of the sewage works configuration, and in particular the sludge treatment process, will generally be necessary to identify streams within biological nutrient removal sewage works processes which offer the appropriate characteristics for P-recovery : high soluble phosphate concentration, low suspended solids, a significant proportion of the sewage works inflow phosphorus present in the stream in question. This is often not easy as sewage works operators do not usually have data concerning phosphorus concentrations, or even flow volumes, for the different streams from and between different operating units of the sludge treatment process.

Yasmin Jaffer (Thames Water, UK) et al. presented results of a study of **Slough municipal sewage works, UK**, which enabled assessment of P-recovery potential and its implications for improving biological P-removal operation. Bernd Heinzmann (Berlin Wasser Betriebe, Germany) examined **different possible installation points for P-recovery** in the large biological P-removal sewage works of Wassmansdorf, Berlin, which operates anaerobic sludge digestion (methane production). He suggests that the mixing of several existing streams and the use of pre-digestion holding tanks can optimise the P-recovery potential, and also the positive impact of P-recovery on sewage works operation.

The definition of configuration for P-recovery installation will take account of impacts on plant operation, in particular reduction of soluble phosphate flows returning from the sludge treatment line to the head of the sewage works (thus reducing the efficiency of the biological P-removal process). P-recovery appropriately installed can eliminate most of this return stream.

The study of a number of real cases of sewage works, through full mass and flow balances for phosphates (soluble and total), calcium,

iron, ammonium, suspended solids, for both the biological P-removal process and the sludge treatment line, appears as a key research area to identify the potential and constraints for P-recovery from municipal sewage.

5.3 Potential for P-recovery from sludge incineration ashes

Sewage sludge incineration ash contains up to 7% phosphorus (P), compared with 13 – 17.5% P in currently available mined phosphate rock²¹.

Willem Schipper (Thermphos BV, The Netherlands) et al. examined the feasibility of recovering phosphates from sewage sludge or sludge incineration ash in The Netherlands by recycling into the Thermphos BV phosphate industry process at Vlissingen. They concluded that **iron, copper and zinc levels are major obstacles**, because significant levels of these elements are incompatible with the Thermphos process. High iron levels are also incompatible with other existing phosphate industry processes or with use as fertilisers. Copper and zinc would also be problematic.

High iron levels can probably be avoided, as these are the consequence of mixing of sludges from sewage works using iron for chemical P-removal with sludges from works using biological P-removal or using aluminium salts. The development of separate sludge management streams at the national level is theoretically feasible, but would however require significant investments in sludge transport, storage and treatment installations, as well as changes to water company policies and to contracts with sludge treatment operators. **Aluminium is not a problem for the Thermphos process (although this is not true for other recycling pathways : fertilisers, other phosphates industry processes)** and the widespread use of aluminium salts instead of iron salts for chemical P-removal in sewage works is technically feasible, although the increased chemical purchase costs for water operators would have to be compared with the benefits of P-recycling. However, copper and zinc levels in municipal sewage appear as structural obstacles to the significant use of sludges or sludge incineration ashes by Thermphos, as levels

²¹ CD paper Schipper

of these elements in waste waters are related to factors such as the composition of domestic piping. The recovery of phosphates by a precipitation process within sewage works (as calcium or aluminium phosphates, compatible with the Thermphos process) would avoid these problems, as levels of copper, zinc or other contaminants in such precipitates are expected several orders of magnitude lower than in sludges or sludge incineration ashes.

Indeed, calcium phosphates precipitated using the Crystallactor® process from a side-stream supernatant at Geestmerambacht municipal sewage works (see above) are already recycled by Thermphos, and contain low levels of iron, copper, zinc and heavy metals.



Willem Schipper (Thermphos BV, The Netherlands) presented pathways which would enable phosphates to be recovered in a form compatible with industrial recycling

5.4 Technical perspectives – phosphate precipitation from liquid streams

Phosphates can be precipitated from solution from liquid streams in sewage or manure treatment works as :

- **calcium phosphates.** These are the same material as in mined phosphate rock and, subject to being produced in appropriate physical and chemical form (pellets and not fine powders or sludges, relatively high P content, low levels of iron, copper, zinc ...) can readily be used by the phosphate or fertiliser industries to replace mined rock (subject to logistical

constraints – distance of transport to nearest potential user)

- **struvite** (magnesium ammonium phosphate = MAP) and potassium struvite (potassium ammonium phosphate). Struvites tend to spontaneously precipitate in sewage works and manure treatment installations, so that operators readily regard their precipitation for recovery as an attractive and feasible option. Cannot be used by the phosphate industry, but can either be used directly as a slow-release fertiliser, or used in fertiliser manufacture.
- **iron phosphate** – discussed above
- **aluminium phosphate.** Can be used as a raw material (subject to the same physical and chemical requirements as for calcium phosphates, above) by Thermphos, Vlissingen, The Netherlands, in their phosphorus furnace process²² but cannot be used in other phosphate industry or fertiliser factories.

The Conference confirmed that calcium phosphate and struvite precipitation were the routes for P-recovery currently perceived as most promising, and where most research is underway. Both pathways are examined in Scope 41.

A workshop session was devoted to **struvite chemistry** applied to P-recovery, with detailed papers presenting laboratory chemical studies from Doyle, Parsons, Ohlinger, Wentzel, Celen, Matysek, Stratful, Tünay and Wu on the Conference CD. The papers by Jaffer, Burns, Villalba, Battistoni, Nawamura, von Munch, Ueno and Mishina also look at struvite precipitation at the application level. The workshop also saw a demonstration of the “Struvite 3.1” computer model which allows precipitation potentials to be calculated from ionic strengths and other waste water data.

The workshop was able to identify key factors which influence the technical and economic feasibility of struvite precipitation as a pathway for P-recovery :

- **low suspended solids**, as these interfere with efficient struvite precipitation and with the

²² CD paper Schipper

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formation of a product in a form suitable for handling and recycling (pellets), as well as resulting in the presence of undesirable organics in the recovered struvite

- **optimising magnesium addition** : magnesium addition (chemical purchase) is probably the highest operating cost for struvite recovery processes, and a key objective is to optimise the Mg added : P recovered ratio. Also other cheap sources of magnesium (seawater, industrial byproducts ...) may offer significant advantages
- **optimising pH adjustment costs** : chemical addition for pH increase (eg. sodium hydroxide) to generate struvite precipitation is another significant cost and the objective is to minimise or avoid this. If a liquid stream with high dissolved CO₂ can be used then significant pH increase can be obtained by degassing (eg by aeration), thus avoiding chemical costs.

The session devoted to **calcium phosphate precipitation** included papers examining the chemistry of calcium phosphates in waste water contexts by van der Houwen, Plant, Koutsoukos, Moriyama and Song, as well as operating experience from calcium phosphate precipitation reactors from Gaastra and Piekema.

Key factors for the technical and economic feasibility of calcium phosphate precipitation appear as :

- **avoiding calcite** (calcium carbonate) interference. The Crystalactor® process to date (eg at Geestmerambacht) requires acidification of the feed stream before it enters the reactor (where the pH then has to be taken up to 8-9) in order to remove CO₂²³. This involves chemical costs which are economically and environmentally too high.
- **lowering reaction pH** : the need for a high pH in the reactor to obtain calcium phosphate precipitation implies high chemical costs.
- **interference from other inorganic ions and**

organic molecules present in waste waters

- balance and changes between **the different forms of calcium phosphate precipitated**

The papers presented showed that **understanding of the chemistry** behind these different operating constraints is rapidly improving and there are reasons to hope that, through factors such as the use of seeding materials, modified reactor design, selective binding of certain interfering chemicals, the work underway will enable significantly more efficient precipitation processes to be developed within a few years.

These factors, for both calcium phosphates and struvite, combine with the requirement identified above of locating or generating a liquid stream within biological nutrient removal sewage works which offers high soluble phosphate concentrations, low suspended solids, and contains a significant proportion of the plant's total phosphorus through flow.

5.5 Technical perspectives for P-recovery – other routes

As well as the well-identified P-recovery routes indicated above (phosphate precipitation from a P-rich stream in sewage works operating biological P-removal), there are a number of other possible routes for P-recovery. **These include P-recovery from sewage sludges or sewage sludge incineration ash, and processes aimed at recovering phosphates from sewage works “mainstream” flows.**

Lorenzo Liberti (Barti Poytechnic, Italy) et al presented the **REM-NUT® brine-regenerated ion-exchange process, adapted for P-recovery as struvite**, which could be applied to sewage works main flow (discharge after secondary biological treatment by activated sludge or trickling filter processes) as a tertiary process for P-removal. He concludes that the REM-NUT® process configured for P-recovery would allow P-removal down to EU discharge requirements at a cost competitive to chemical P-removal, as well as improving suspended solid removal. Liberti is now looking for funding to build and test a 240 m³/d fully auto-

²³ See eg. papers by Gaastra and Guiffre from the First P-Recovery Conference 1998, on CD

Recovery of phosphorus from

mated mobile plant. The process is a next phase development of the REM NUT process that was extensively tested in the 1980s. The original process never made it to full scale as the unbalance between P and N in municipal wastewater due to costs. In the new P-driven REM-NUT® cation and anion exchangers are again used here they are sized to allow for the removal and recovery of equimolar amount of NH_4 and PO_4 ions from wastewater and excess ammonia is left to conventional treatment processes such as bio(de)nitrification and air stripping). The process removes in excess of 95% of phosphate from wastewater and produces a concentrated stream, which can then be precipitated a struvite. An economic assessment was also reported giving net costs of € 0.048 m^3 for the process which, for an 11000 m^3/day plant, made it competitive to chemical phosphorus removal (€0.052/ m^3). This cost though included the sale of struvite, whereas if this couldn't be achieved the cost increased to €0.084/ m^3 .

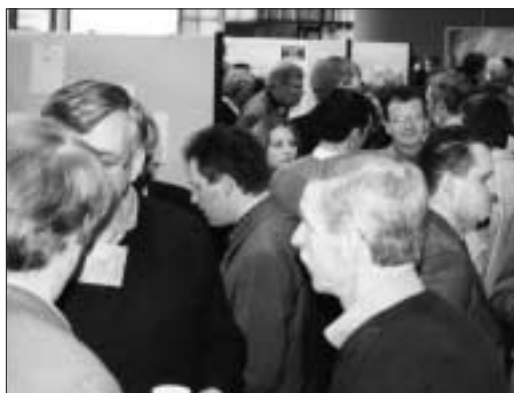
Arup Sengupta (Lehigh University, Bethlehem, USA) presented results using a **Polymeric Ligand Exchanger (brine-regenerated ion-exchange) system** at Bethlehem sewage works, Pennsylvania, USA, using a specially designed phosphate selective resin. One of the major limitations of conventional anion exchange processes is that sulphate is always present in wastewater in much higher concentrations than phosphate and preferred by the anion exchange resins over phosphate. To overcome this competition the resin is in this case loaded with copper which increases the affinity of phosphate over sulphates, leading to a 10x increase in bed life over other resins. The resins gave a ~95% removal of phosphate from a dilute wastewater stream (~2.5 mg/L P) and produced a concentrated phosphate stream which could then be precipitated as either struvite or calcium phosphate. The costs of the treatment, however, raised much discussion at \$0.3 per 1000 US gallon.

Tomotake Takai (Takeda Chemical Industries Ltd, Japan) et al. presented a process for recovering phosphates using a **selective adsorbent mainly composed of zirconium hydroxide and ferrite compounds**. However in their work, they extrac-

ted soluble phosphates from sewage sludge using sulphuric acid hydrolysis and heat treatment. After regeneration of the adsorbents using sodium hydroxide, phosphates sodium phosphates were produced, suitable for industrial applications. 68% of phosphorus present in the sewage sludge was recovered using this treatment process, generating a sodium phosphate product containing 89% sodium phosphate (17%P), 0.7% iron only, and very low levels of heavy metals.

Bengt Hultman (Swedish Royal Institute of Technology, Stockholm) et al. presented improvements to the economic efficiency of **three recently developed processes : Krepro®²⁴, Cambi/KRE-PRO and Bio-Con**. **The first two deal with sludge treatment recovering iron phosphate ; the last (Bio-Con) with sludge incineration ash recovering phosphoric acid**. Not surprisingly, economic optimisation led away from chemical additions (e.g. sulphuric acid, iron salts, and alkali) needed at various stages in these processes and towards partial bio-P substitution. Also looked at, among others, was a hydrogen sulphide process partially driven by the biological reduction of sulphate but this was felt to be too hazardous to operate.

Paul Devine and Elaine Dick (Questor Centre, Queen's University Belfast, Northern Ireland), presented an ongoing research project into enhancing the content of phosphorus found in biological phosphorus removal sludges. **The work aims to combine biological and chemical processes where so that the bacteria will act as a seed for phosphate precipitation reactions**. The work,



²⁴ CD paper Karlsson

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which is at an initial stage, aims to optimise the anaerobic phosphate release so as to generate high local phosphate concentrations around bacteria cells, so that the addition of calcium or magnesium will lead to the precipitation of phosphates onto the cell surface. Previous work on heavy metal removal gives a good idea of the potential of the process.

Zsofia Ban (Göteborg University, Sweden) et al. et al presented work **precipitating struvite from human urine²⁵, generated by separative sewerage collection systems** (where urine is collected separately from solid and other household wastes, instead of having all wastes mixed with large amounts of water in unitary sewerage networks). Regenerating mineral adsorbents were also tested to enable ammonia removal, for nitrogen recovery. Jac Wilsenach (Delft University of Technology, The Netherlands) provided an overview of current initiatives in Europe to collect separately urine, underlining that the development of such systems would significantly facilitate P-recovery from this source.

Tom Arnot et al. (University of Bath, UK) presented a proposed sewage treatment process involving anaerobic digestion (methane production), solid/liquid separation, and then **reversible phosphate adsorption using fly ash**, the objective being to produce a phosphate-rich solution for P-recovery by precipitation.

6. Economic perspectives

As Jeanmaire concluded, the sale price of the recovered phosphate product is unlikely to be the main driver for P-recovery, with other factors such as reducing sludge production and improving sludge management, pressure for sustainable development (recycling) and improvement of biological P-removal operation probably being the main driver in most cases.

Nonetheless the potential sale value of the recovered phosphate product is a significant factor in

evaluating the economics of possible P-recovery processes.

Gaterell et al (paper on CD and in Environmental Technology 2000, Vol. 21. pp 1067-1084, summarised in Scope 40 page 10) indicate that prices for phosphate fertilisers and for mined phosphate rock as follows²⁶ :

- triple super phosphate fertiliser : price at port 142 UK£/tonneP₂O₅ ; price delivered to farm 190-200 UK£/tonneP₂O₅ that is approx. 530 €/tonneP at port, 710 – 745 €/tonneP delivered
- mined phosphate rock : price at port 90 UK£/tonneP₂O₅ = approx. 340 €/tonneP.

Crook et al (Anglian Water, UK), presented lab studies of phosphorus release from sewage sludges using acetic acid, concluding that P-recovery from biological nutrient removal sewage works sludge could be economically viable if the recovered product reached a sale price of UK£86 /tonne of calcium phosphate, which equates to approx. 700 €/tonneP.

Ueno (see above) stated that struvite (13% citric acid soluble P) produced in full-scale P-recovery plants operating in Japanese sewage works is sold to fertiliser companies for **250 €/tonne with transport costs from the sewage works covered by the purchaser (approx. 1,900 €/tonneP)**. The recovered struvite is sold as a premium value fertiliser for rice and vegetable cultivation. The product is marketed by two fertiliser companies, who emphasise in their advertising that it is an environmental recycled product ("Green MAP"). The fertiliser, after mixing with other products to provide a potassium content, is then sold to the public for 100 – 200 € per 20 kg bag.

Von Munch estimated that struvite recovered from pig manures or sewage in Australia should be marketable at 234 – 500 Australian \$/tonne (by comparison with either wholesale agricultural or retail specialist application fertiliser prices), that is approx. 1,000 – 2,000 €/tonneP.

Liberti quoted price estimates of US\$800/tonne (approx 6,500 €/tonneP) given by

²⁵ Scope 40 page 9 • ²⁶ Molecular weights are : calcium 40, phosphorus 31, oxygen 16, magnesium 24, nitrogen 14. Thus 1g P = 3.1g P₂O₅ = 2.3g Ca₅(PO₄)₃O = 4.4 g dewatered struvite MgNH₄PO₄ = 7.6g struvite MgNH₄PO₄·6H₂O



the US Environmental Protection Agency in the late 1980's, but estimated that US\$500/tonne (approx 4,000 €/tonneP) would be a reasonable figure to expect in Europe.

Clearly, the potential market value of the recovered product from a P-recovery process remains essentially unclear to date. Boundary limits can probably be identified, at the lower end as the price of mined phosphate rock on arrival at European ports, at around 340 €/tonneP ; in the middle range as the price of agricultural fertilisers, at around 700 €/tonneP. Higher prices may nonetheless be achieved in some cases, as is already shown by Unitika Ltd (Ueno's paper) in Japan, where a market can be identified for the product either as a specialist component for supply to a fertiliser manufacturer, or by direct retail sales of the product as a specialist fertiliser for certain local applications.

In many cases, it was felt, water companies would not wish to be involved in "marketing" recovered phosphates (eg. as a specialist fertiliser), and may tend to be happy to treat it as a by-product and be satisfied with a destination which allows it to be reliably sold at a relatively low price.

7. Perspectives for P-recovery from manures and of the sources

The quantities of phosphates potentially available for recovery and recycling in animal manures are significantly greater than those in municipal sewage (respectively around 2 million and 450,000

tonnesP/year for Europe). Phosphates are technically potentially easier to recover from manures than from sewage (manures from livestock production are generally less diluted than sewage, and contain much lower concentrations of diverse organic and inorganic contaminants which may complicate the chemistry of recovery processes).

However, phosphate recovery from pig manure is made more difficult because around three quarters of the phosphate content is generally in the solid fraction of the manure, so that some kind of biological or physical digestion process is necessary to render the phosphates soluble before a precipitation recovery can be operation.

Julian Greaves (Institute of Grassland and Environmental Research, UK) et al. presented work on **biological processes** comparable to "biological P-removal" in sewage works capable of increasing by a factor of three the proportion of phosphates in solution, and thus potentially available for recovery by precipitation.

Kai Hohn (Fraunhofer Institut Chemische Technologie, Germany) presented a process currently being developed for pig manures involving a methane-producing digestion stage followed by solid/liquid separation. The solid fraction is used for compost production, whilst the liquid fraction is **membrane treated** allowing a **high-quality phosphate solution** to be produced, from which struvite can be precipitated, for resale as a fertiliser.

Several North American delegates underlined the considerable interest in recovering and recycling phosphates from animal wastes. Burns et al. (University of Tennessee) presented experimental work showing that over 91% of soluble phosphate in raw pig manure could be precipitated as struvite.

Henryk Gorecki et al. (Wroclaw University of Technology, Poland) presented work in Poland and Sergei Kalyuzhni (Moscow State University) et al., work in Russia, showing that interest in P-recovery from manures is active in these countries, which have a number of very large, concentrated pig farms. Ong and Suhaimi (Malaysian

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Agricultural Research Institute). confirmed that there is also an active interest in Malaysia.

Shulze-Rettner et al (Germany) presented the potential for P-recovery from animal manures in Germany and gave figures for typical chemical compositions of raw and filtered manures. In The Netherlands, a full scale plant is already operational recovering potassium ammonium phosphate from 700,000 tonnes/year of veal calf manures at Putten²⁷. Hans de Haan (DEP Stichtung) presented the **construction of a full-scale plant to recover phosphates from chicken manure** from around 600 poultry farms currently being built in The Netherlands (ZLTO/Mestac project, treating around 300.000 tons of poultry litter per year)

Elizabeth Von Munch et al. (Brisbane Water, Australia) presented a **business plan aiming at recovering and recycling phosphates from 105 large piggeries, as well as from sewage works, in Australia** – this project is currently negotiating funding with investors.

Marie-Line Daumer et al. (CEMAGREF, Rennes, France) presented work into **mass balances for phosphorus and other elements in biological pig manure treatment in France**, showing that most of the phosphorus in the manure ended up in sludges, where it could become soluble during holding.

Kelvin Webb et al. presented detailed characterisation work on manures in Australia, providing optimal conditions for phosphate precipitation as struvite to be defined.

Gara Villalba (University of Barcelona, Spain) et al. presented studies **into P-recovery from industrial waste waters at a carmin red dye manufacturing plant** (near Barcelona, Spain) by struvite precipitation. At the First P-Recovery Conference (Warwick, 1998), Donnert presented experience of phosphate recovery from industrial waste waters from the Mercedes car factory in Gaggenau, Germany (from metal surface preparation in paint workshops)²⁸.

A number of Conference delegates were from different chemical or food industry companies

having high-phosphate waste streams, and expressed significant interest in phosphate recovery. **Industrial waste streams often offer relatively high phosphate concentrations**, with predictable and/or low levels of other ions, and the operators are generally subject to stringent discharge requirements, thus rendering the development of P-recovery processes cost-effective.

The main obstacle to the development of P-recovery from manures and agricultural waste streams, on the other hand, is the failure of regulators in many cases to introduce or to enforce discharge constraints, for political reasons. In this context, farmers and livestock producing companies are of course not prepared to pay the additional costs which P-removal implies. However, many conference delegates believe that this situation is likely to change, with a progressive tightening of discharge constraints for the agricultural sector, to gradually bring it into line with the water industry.



Rainer Schlze-Rettmer presented the potential for P-recovery from animal manures in Germany. Photo : Full scale pilot phosphate recovery installation at Obrigheim sewage works, Germany. Photo R. Schulze-Rettmer, Consulting Chemist, Germany. Aachen



Commerically operational full-scale struvite recovery installation at Shimane Prefecture sewage works. Photo : Unitika Ltd, Japan.

²⁷ Schuiling paper from the First P-Recovery Conference 1998, on CD • ²⁸ Environmental Technology July 1999, vol. 20, n°7, 735-742