PHOSPHORUS RECOVERY
– EXPERIENCES FROM EUROPEAN COUNTRIES

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ABSTRACT
The interest in recovery and reuse by sludge fractionation has increased in recent years, largely due to environmental and political considerations. This article is a survey of the status concerning phosphorus recovery, looking into national policies and experiences in different European countries to find different factors influencing the development of phosphorus recovery. The ambivalence of sewage sludge as carrier of both nutrients and pollutants makes the direct use of biosolids is discussed controversially in many Europeans countries. Increasing restrictions of sludge utilization in agriculture or landfill promote new alternatives for sludge disposal.
The optimized sludge disposal option needs to fulfill to be the most environmental option, include social acceptance, be economical and have a feasible technical solution. At present there is no such technology fulfilling all this requirements. The driving force parameters for phosphorus recovery vary in the national context, in early stage there seems to be driven by legislation and technical feasibility (some cases also economic feasibility), while for next stage, full-scale implementation the most important factors seems to that economic feasibility, the environmental sustainability, and the social acceptance. The rate of development is also depending on these factors, especially legislation.
Several pilot plant studies and lab-scale experiments are performed around Europe. The last two years many research teams have continued or started their investigating on the issue and some are discussed in this paper.

KEYWORDS
Phosphorus recovery, Sewage sludge, Sludge treatment, Sustainability

INTRODUCTION

There is still a long way to go to achieve a sustainable society. One aspect of sustainability is to economise with scarce resources (Balmér, 2004). The known reserves of phosphorus are estimated to last 100 years with present utilisation rate (Driver et al., 1999). The fertiliser industry is the dominating user of phosphate rock and agriculture is the main end user of phosphorus.
An important aspect is that most of the phosphorus containing apatite also contains cadmium. Phosphorus mining brings inevitable more cadmium to the biosphere, which causes severe local environmental effects. This means that even if there is no urgent need for phosphorus recovery, there are good reasons to economise with the resource. Another reason to recover phosphorus is that landfills may easily be a diffusive source for phosphorus discharge to surface and groundwater.
The most valuable element in the sludge is phosphorus and recovery of phosphates from sludge by chemical or microbiological /chemical precipitation in the water line and recovery from the sludge is according to Rulkens (2004) a possibility towards a sustainable sludge management. The technologies to recover phosphorus from wastewater and sludge are in an initial phase of development and it is reasonable to believe that further improvements are possible (Balmér, 2004).

In most European wastewaters phosphate has concentrations of typically 10 mg P/l or below. Effluent standards from WWTP are normally in the range of 0.5-1 mg P/l, i.e. removal efficiencies of over 90 % have to be achieved. In the Scandinavian countries and in some cantons in Switzerland (Zurich especially) have lower levels for phosphorus discharge (0.2-0.3 g/m^3). In order to reach such results the chemical precipitation for phosphorus removal (mainly with iron salts) has been preferred to the biological P-removal, consequently phosphorus is strongly bound to the metal ions. Countries as Germany, England, France and Italy are mainly using biological phosphorus removal. Biological processes can be highly selective, and can achieve easily low concentrations. A disadvantage is that phosphate is only concentrated in the biomass. A combination of a biological process for concentrating the phosphates and a physical-chemical process for recovery seems therefore to be the best option for phosphorus recovery (Stark et al., 2002b).

Methods to recover phosphorus from WWTP
In general, there are two possibilities to recover phosphate from municipal wastewater (Hultman et al., 2001a; Brett et al., 1997);

- Recovery in wastewater treatment
- Recovery from the produced sludge

Phosphate recovery from untreated sludge are for instance that phosphates may be removed in the main stream after biological treatment as calcium phosphate (use of for instance Crystallactor), use of ion exchange technology (as REM-NUT) for the production of magnesium ammonium phosphate. It is also possible to produce phosphorus products (calcium phosphates or magnesium ammonium phosphate) by treatment of a fraction of the return sludge from an activated sludge plant with enhanced biological phosphorus removal. Anaerobic treatment of the return sludge fraction gives rise to release of phosphorus, which can be recovered in a separate step. The sludge produced from a wastewater treatment plant may be used directly as a resource in agriculture if the amount of pollutants is low in the sludge. Phosphorus in sludge is bounded both biologically and chemically.

Phosphorus recovery from wastewater treatment plant sludge generally follows three steps (Stark, 2002) (see Figure 1):

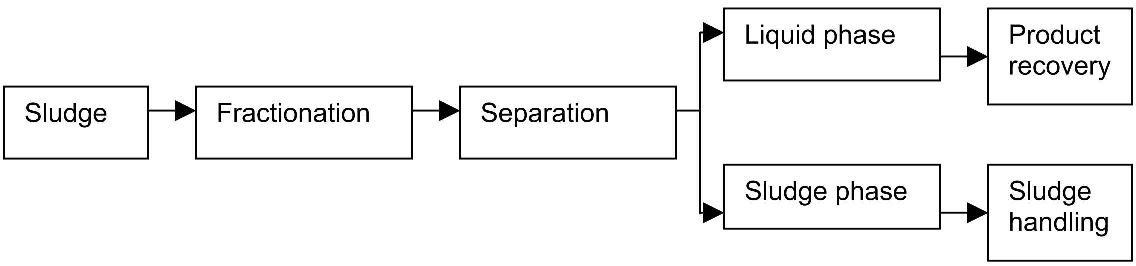

Figure 1. General scheme for sludge fractionation and product recovery (Stark, 2002).

1) Transfer of soluble phosphorus compounds into biomass (enhanced biological phosphorus removal, by algae) or into chemically bound phosphorus compounds, through addition of precipitating agent.
2) Solubilisation of sludge bound compounds (including phosphorus compounds) by different methods through the use of physical, mechanical, biological or chemical means. During this step for instance phosphorus is transferred into a relatively small stream compared with the influent

flow. The phosphate concentration in this stream may be 10-50 times higher than the influent phosphate concentration.

3) The phosphate-enriched stream may also contain a lot of other components such as precipitating agents, organic materials and heavy metals. Separation technologies such as chemical precipitation, crystallisation, ion exchange or membrane technology must be used to obtain a reasonably pure phosphorus product.

STATUS AND EXPERIENCE IN EUROPEAN COUNTRIES

The Netherlands is among the pioneer countries in the field of phosphorus recovery from sludge with experiments performed in full-scale plants at municipal WWTPs (i.e. Geestmerambacht –230 000 p.e-; Heemstede -35 000 p.e-; Westerbork). In the Netherlands the regulations governing the maximum heavy metal content of the sludge from WWTP going to agricultural reuse are among the most stringent in Europe. Already since 1995 agricultural spreading of sewage sludge in the Netherlands is no option. One of the consequences of this situation is the massive use (around 60%) of incineration (Roeleveld et al., 2004).

Thermphos International B.V from The Netherlands has stated the objective of replacing 20% of its current phosphate rock consumption by recovered phosphates, in order to reduce the consumption of phosphate rock and to close the phosphorus cycle (Roeleveld et al., 2004). Moreover, the recyclable product must be calcium phosphate or aluminium phosphate and not struvite. From a Dutch study it became clear that all end products from the final sludge treatment do not provide a good source of secondary phosphate, whereas P-recovery should be extracted sludge goes to final sludge treatment. As a consequence of this situation, the process that must be used preferably in Holland is the side stream process according to Schipper et al., (2001).

Much research has been carried out over the last years. Experiments were performed on bench scale units for instance in Karlsruhe Research Center, Germany (Donnert and Salecker, 1999), Thames Water, UK, (Williams, 1999), West Bari WWTP, Italy (Liberti et al., 1986) Water Works Zwickau, Germany, (Jeanmarie, 2001) Berline Wasser Betriebe, Germany, (Heinzmann, 2001) Öresundsverket WWTP, Sweden (Karlsson, 2001) Owschlag WWTP, Germany, Wassmandorf WWTP, Germany (Scope, 2004a) and even on full-scale plants Geestmerambacht WWTP, the Netherlands, (Giesen, 1999) Treviso WWTP, Italy (Battistoni et al., 2001, Scope, 2004b), Westerbork WWTP 1988–1991, the Netherlands, Heemstede WWTP that is stopped today (Jeanmarie, 2001).

Economical aspect

Phosphorus recovery can be seen as technically feasibly but the economic feasibility of phosphorus recovery from sewage can still be judged as dubious (Roeleveld et al., 2004). Most important reason is that the prices of the available nowadays techniques (in Euro/tonne P) are much higher than compared to the prices of phosphate rock. Private companies consulted in France and England (Jeanmarie, 2001) permit to assert that the market value of the recovered product will not be the first motivation for the water industry to install phosphorus recovery. Moreover, the survey carried out throughout Europe reveals that the motivations expressed by the water industry are variable in each country. Hultman et al., (2003) has estimated that phosphorus recovery would increase the total costs for total services of potable water and sewage by 1%. Balmér (2004) writes that if the economy of a system, which may look environmentally attractive, is miserable, this may at least be an indication that precaution is recommended before such a system is adopted. The most expensive studied systems by are source-separating systems (Balmér et al., 2002).

Legislation context
When there is no direct economic driving force, regulations can be a stimulating factor. Both Germany and Sweden have announced national objectives for phosphorus recovery for recycling from sewage. Sweden's action plan centers on recycling phosphorus to land through sewage sludge use in farming, whereas the German Federal Environment Ministry (UBA) suggests recovery for recycling in sewage works (SCOPE, 2003a). The UBA suggests that existing taxes on wastewater could be used to support the technical development of phosphorus recycling.

The Swedish EPA (Environmental Protection Agency) action (SEPA, 2002) has proposed an intermediate target for P-recycling that by 2015, at least 60 % of the phosphorus in wastewater shall be restored to productive soil, of which half should be returned to arable land. It was also suggested to implement at least 3 phosphorus recovery systems to be tested in full scale by 2008 and that at least half of the municipalities in Sweden shall have accepted strategies of recycling of nutrients in sewage. The action plan is suggested to be evaluated in year 2006 and have a final action plan ready in year 2008. The case is at present prepared by the Swedish Government office according to Prop. 2002/03:117.

Both the Swedish and German authorities recognize that phosphorus can be recovered for recycling by various processes including recovery from wastewaters in sewage works or from sewage sludge incineration ashes. The environmental authority of Åland (an autonomous province of Finland) has also proposed a goal of 50 % recovery of phosphorus from sewage (Miljöbyrån, 2002).

Technical aspect-Processes for phosphorus recovery
Stockholm Water (the local water and sewage company in Stockholm) has shown interest in Aqua Reci process and conducted laboratory and pilot plant scale experiment (Stendahl and Jäfverström, 2004). Aqua Reci process uses supercritical water oxidation (SCWO) to decompose organic contaminants, followed by chemical process to recover components in the inorganic residual ash, like phosphates and coagulants. Estimated total investment for the SCWO process is 8.5 MEUR and for the recovery process to 600 000 EUR.
Stark and Hultman, (2003) have also investigated and got further proofs to point out that it is possible to recover phosphorus from sludge by combination of SCWO process and alkaline leaching and by adding lime. The main problem relating to SCWO is corrosion and salt deposit. Svanström et al., (2001) shown that the life cycle assessment (LCA) of a SCWO processing of sewage sludge is strongly dependent by the surrounding of the actual SCWO unit and that the life cycle is interesting from an environmental point of view.

Another method to recover phosphorus from sludge is KREPRO (Recktenwald and Karlsson, 2003), which interested the city of Malmö in Sweden for implementation. Due to lower phosphorus recovery demand proposed by the SEPA the project was postponed in 2002. Estimated investment cost in 1999 was 7.3 MEUR for the process. Full-scale experiments were conducted, producing ferric phosphate and tests show that its product has considerable fertilizing effect (Hansen et al., 2000). In contrast to this a study performed in Norway by Krogstad et al., (2003) showed Fe rich sludge had the most negative value for plant uptake.

Furthermore, Seaborn process developed in Germany (ATV, 2003; Scope, 2004a), treats organic material (such as sewage) to produce biogas by fermatation (methane), heavy metals removal (by sulphide precipitation) and ammonium phosphate for fertiliser as struvite or calcium phosphate. Another interesting method looked into is, for instance, Sulphate reducing bacteria (SRB) could effectively be used for phosphates release from Fe-P sludge (Suschka et al., 2001).

Most processes need chemical consumption in order to recover a phosphorus product. Studies have shown that systems with thermal treatment and dissolution of phosphates from the sludge by use of acids have about the same chemical demand for phosphorus recovery. The demand for chemicals is much dependent on the type of method for phosphorus removal (biological or chemical) and increases linearly with the dosage of precipitation agents (Hultman et al., 2001b; Stark et al., 2002a).

- Incineration
In Denmark, the traditional disposal for agricultural use has changed to other disposal routes, as thermal treatment, drying and/or incineration due to more strict legislation (Simonsen and Bruus, 2003). These tendencies are expected to appear all over Europe in the years to come. Switzerland has, for instance, banned all use of sludge as fertilizer to be effective from 2006 (WE and T, 2002) and the environmental minister Ulrich Müller in Baden Württemberg has recommended that all sludge should be incinerated rather than spread on farmland. Another important parameter for the development in Denmark has been the introduction of taxes in relation to sludge incineration and sludge landfilling. In Sweden landfilling will be banned by 2005 and has very stringent rules for limiting values of metal concentrations in sludge used in agriculture.

Growing difficulties in sludge utilization in agriculture or use of landfill make incineration an attractive alternative for sludge disposal. In Darmstadt, Germany research is going on about phosphorus recovery from ash (Schaum et al., 2004). The most promising way seems to be the release of phosphorus with acids or bases. Levlin et al., (2003) have also conducted similar experiments. In the BioCon process ash from sludge incineration is proposed to be leached with acid and the content in the leachate separated with ion exchange technology (Levlin, 2001). However in the sludge incineration plant built by the BioCon Company in Falun, the phosphate recovery process based on ion exchange has been abounded (NyTeknik, 2002). The proposed phosphate recovery process is to leach the ash with sulphuric acid and recover the phosphate as iron phosphate. Limoni et al., (1999) has studied Ion Exchange Recovery of Aluminium in the IERAL process in Italy. Kowalski et al., (2003) has studied thermal utilisation of sewage sludge in Poland and recovery of phosphorus from the ash after incineration. Braguglia et al., (2003) in Italy is modeling sludge incineration. McCahey et al., (2003) in UK is investigating the potential of gasification for sewage sludge within the European Commission FP5 Programme, using laboratory and pilot plant scale studies.

In table 1 technology are presented with different recovery potential and different development possibilities in phosphorus recovery studied by the German project team (ATV, 2003).

Developing phosphorus recovery technologies it is close to the field of sludge minimization and recovery of other products from sludge. For instance, Onyeche and Schäfer, (2003) studied energy production (methane gas) and savings from sewage sludge treatment. This study was performed due to a new German environmental regulation from year 2005; landfilled wastes should not contain more than 5 % organic substances.
Marchioretto et al., (2003) in the Netherlands has performed bio- and chemical leaching experiments of heavy metals from digested sludge. Boura et al., (2003) in Greece has investigated alternatives for final disposal of sewage sludge in developing new construction materials, using Portland cement. Chauzy et al., (2003) presented Bio THELYS, a new sludge reduction process by thermal hydrolysis, and the laboratory experiments in Champagne, France showed minimization of sludge production up to 70 % on sludge. Kemicond is another method for reducing sludge volumes and enhancing the sludge quality, which will be tested in Sweden (Manhem and Palmgren, 2004).

Table 1. Increased need and advantages of systems for phosphorus recovery from wastewater, sludge and ash (modified from ATV, 2003).

System	Increased cost and need	Advantages	P-product
Recovery from main stream			
Post precipitation	• Increased use of measurement and control techniques • Higher maintenance cost (for precipitation agents, and possible neutralization chemicals)	• Decreased discharge of wastewater i.e. decrease flow of phosphorus	Calcium phosphate
Crystallisation	• Increased use of measurement and control technique • Higher maintenance cost (for graft material, and possible chemicals for pH-adjustment)	• Decreased discharge of wastewater i.e. decrease flow of phosphorus	Calcium phosphate
Recovery from side stream			
Phostrip-process	• Cost for adjustment to Bio-P process • Higher maintenance cost	• Saving of precipitation agents	Calcium phosphate
Process water treatment	• Increased use of measurement and control techniques	• Decreased load of process water (N and P) • Advantages of maintenance (decreased precipitations)	
Crystallisation	• See crystallisation in main part • Cost for adjustment to Bio-P process	• Saving of precipitation agents	Calcium phosphate or magnesium ammonium phosphate
Recovery from sewage sludge			
KREPRO-process	• Chemical addition for recovery of phosphorus • Thermal energy to heat sludge	• Recovery of precipitation agents • Possible to replace extern coal source for denitrification • Decreased cost for sludge handling due to decreased amount of sludge	Iron(III) phosphate
Seaborne-process	• Chemical need for phosphorus recovery • Very complex process method	• Production of fertilser or raw material for fertiliser • Recovery of biogas; decreased N-load	Magnesium ammonium phosphate (MAP)
Aqua-Reci process	• High consumption of oxidation agent • Very high need of raw product	• No organic residual product	Iron Phosphate or calcium phosphate
Recovery from ash (sludge incineration)			
BioCon-process	• Chemical need for phosphorus recovery • Most cost with sludge incineration compared to co-incineration	• Production of fertiliser • Recovery of precipitation agents • Decreased amount of ash	Phosphoric acid

Agricultural use
In Europe 55 percent of the total production of sludge is used in agriculture (Lewis and Gattie, 2002). This follows the view in a EU-report (SCOPE, 2003b) that states agricultural use is the best environmental and economic solution for sewage sludge. This sludge disposal option is only lacking in development of agricultural spreading route, and needs improvement of both sludge qualities and public confidence. Research in this field is for instance ReVAQ, which is a project going on in Sweden between municipal water and sewage works, food industries, farmer's organisation, environmental organisation, public, consumers and trade. The project is looking into if it is possible to produce a sludge without harmful substances suitable for agriculture. This kind of research raise the interesting question what are WWTP´s going to be used for and what happens to water not treated at the WWTP?
Furthermore, BIOWASTE (Schmidt et al., 2003) is a project involving 5 partners from 4 EU countries (Denmark, France, Greece, Spain) studying bioprocessing of sewage sludge for safe recycling on agricultural land. Another project also investigating recycle to agricultural land is SAPHYR- a new chemical stabilization process developed by Vivendi Water Systems (Barato et al., 2003), which is based on an acidification of biosolids associated with the addition of nitrite.

DISCUSSION

In order to develop public confidence, the EU is proposing significant tightening of regulations concerning biosolids spreading (currently covered by EU directive 86/278). This means that it will have little impact on countries where national sludge spreading regulations are already much more stringent than existing EU Directive requirements (see Table 2). Implementation costs will however be significant in countries where existing national regulations are only somewhat more stringent or are similar to current EU Directive (SCOPE, 2003b). It is interesting to see that the countries having strict regulations today are the one's that were first investing in phosphorus recovery (especially Sweden and the Netherlands). Italy may be seen as an exception, seem to be driven by technical feasibility.

Table 2. National requirement compared to EU requirements on sludge use

Much more stringent	Denmark, Finland, Sweden, the Netherlands
More stringent	Austria, Belgium, France, Germany, Poland
Similar	Greece, Ireland, Italy, Luxembourg, Portugal, Spain, United Kingdom, Estonia, Latvia

Another interesting aspect, Holland has treatment facilities recovering phosphorus as a calcium salt, which is being used as a raw material from which phosphate salts, are made. Thermophos claim that the recyclable product must be calcium phosphate or aluminum phosphate not struvite. Consequently, it is the industrialist who determines the qualities of the product that must be reached. It is interesting which actors decide about phosphorus recovery. If the industry says they want a specific product, the technology is developed according to the product. While in the case legislation deciding the rules for phosphorus recovery, it may open for more solutions and may also be a product no one wants.

Stimulating factors for P-recovery varies between countries; in the Netherlands phosphate industry is the main actor, for example Thermphos claim that the recyclable product must be calcium phosphate or aluminum phosphate not struvite. Consequently, it is the user who determines the qualities of the product that must be reached. In Sweden and Germany politicians are involved in the process, when there is no direct economic driving force for phosphorus recovery, regulations can be a stimulating factor. Both Germany and Sweden have announced national objectives for phosphorus recovery for recycling from sewage. Sweden's action plan centers on recycling phosphorus to land through sewage sludge use in farming, whereas the German Federal Environment Ministry (UBA) suggests recovery for recycling in sewage works. The UBA suggests that existing taxes on wastewater could be used to support the technical development of phosphorus recycling.

Comparing the strategies between the countries it seems that the Netherlands is focused on side-streams´ processes while in Sweden and Germany there are different options for phosphorus recovery solutions including recovery from wastewaters in sewage works or from sewage sludge incineration ashes, resulting in a variety of phosphorus products, and still no full-scale plant as in the Netherlands.

Further developments in technology for phosphorus recovery are possible and new developments in this area can be foreseen and are for example:

- Improvements regarding efficiency of already developed advanced systems as KREPRO and BioCon and developments of other technically advanced systems as Seaborne and Aqua-Reci. These systems can be constructed for a high degree of phosphorus recovery and sludge volume reduction (and have therefore been of interest to use for achieving a high Swedish goal for phosphorus recovery).
- Development of product recovery from similar systems as PhoStrip (Roeleveld et al., 2004) and combined treatment of phosphate-rich streams from PhoStrip with ammonium-rich streams from dewatering of digester supernatant (precipitation of magnesium ammonium phosphate). PhoStrip can obtain a pure phosphorus product, which is the main requirement for the phosphate industry.
- Combined use of systems as PhoStrip with combined product recovery of calcium phosphates and lime recovery in calcinations.

There seems to be a need for a clear political strategy regarding recovery of phosphorus, as other resources, otherwise the development will continue at very slow pace.

CONCLUSIONS

Sludge management is debated issue around Europe due to e.g. difficulties to obtain consensus on agricultural sewage sludge re-use. The most economic way of P-recycling is agricultural sludge application, but since the environmental sustainability (sludge quality) and social acceptance is lacking there are developments for other sludge disposal methods.

Different factors are stimulating the development of phosphorus recovery. It is clear that the national context (regulations, synergy in the development of new durable techniques, important costs of sludge disposal) strongly influences the possibilities of a large-scale phosphorus recovery. Stimulating factors for P-recovery varies between countries; in the Netherlands phosphate industry is the main actor, in Sweden the environmentalists and politicians, while in for example Italy it seems to be the technical feasibility. The technologies to recover phosphorus from wastewater and sludge are in an initial phase of development and it is reasonable to believe that further improvements are possible.

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