PHOSPHORUS RECOVERY FROM SLUDGE IN SWEDEN – POSSIBILITIES TO MEET PROPOSED GOALS IN AN EFFICIENT, SUSTAINABLE AND ECONOMICAL WAY

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ABSTRACT
Phosphorus recovery from wastewater may be a requirement in Sweden in the future. An intermediate target is that by 2015, at least 60 per cent of the phosphorus in wastewater shall be restored to productive soil, of which half should be returned to arable land. Different strategies and methods to achieve this target are discussed based on reports from the Swedish Environment Protection Agency (SEPA) and with special emphasis on extraction of phosphate from wastewater, sludge and ash at central plants. Some possible improvements are briefly discussed such as the use of certain comparatively clean sludge fractions and use of two-stage technology for the recovery.

KEYWORDS
Phosphorus; phosphorus recovery; side-streams; sludge; Sweden; wastewater

PHOSPHORUS RECOVERY – ONE OF THE GOALS IN SWEDISH SLUDGE HANDLING

In a report from the Committee on Environmental Objectives “The future environment – our common responsibility” (Miljömålskommittén, 2000) 15 Swedish environmental quality objectives were suggested based on the vision of a future with sustainable development. One of the goals was related to phosphorus recycling and it was proposed firstly that 75% of the phosphorus from waste and wastewater should be part of a sustainable urban-rural eco-cycle no later than 2010, and secondly that it should be possible to return it to arable or productive land without jeopardizing human health and the environment.

The Swedish Environmental Protection Agency (Swedish EPA; in Swedish “Naturvårdsverket”) was consequently commissioned to examine, in consultation with the relevant authorities and stakeholders, the issues concerning the environmental and health protection requirements for sewage sludge and its use as well as for restoration of phosphorus to arable land as it was considered that there was currently no technical basis that enabled a quantative and time-framed target to be set up regarding this issue. (from p. 21 in report 5214 from Naturvårdsverket, 2002a).

The assignment resulted in an action plan for recovery of phosphorus from waste (Naturvårdsverket, 2002a). This report was the main report to the project “Satisfactory sludge and phosphorus in an eco-cycle”. Although the commission mainly had the purpose to evaluate phosphorus recovery other components were considered to be important to recover as nitrogen, potassium and sulphur and the role of organic material for instance for energy production. The action plan also considered more stringent regulations concerning toxic substances and hygienisation.

Several reports were written to form the basis of the main report. Related to phosphorus one report was written on sustainable use of phosphorus (Naturvårdsverket, 2002b), one on systems for recovery of phosphorus from waste (Balmér et al., 2002) and one on social-economical aspects of recycling of nutrients from wastewater (Carlsson-Reich, 2002). A seminar was also held on eco-cycling of plant nutrients from urban areas (Mat 21, 2002).

In the action plan it was stated "The long-term aim is to return all nutrients in wastewater that can be recovered back to the soil. What proportion of nutrients in wastewater fractions this constitutes depends on aspects such as the long-term focus of system solutions".

An intermediate target on the way to the long-term aim was formulated:

"By 2015, at least 60 per cent of the phosphorus in wastewater shall be restored to productive soil, of which half should be returned to arable land". This percentage should be considered as a national goal. In order to make allowance for differences in regions within the country and to permit different solutions locally and regionally, the recovery of phosphorus in parts of the country may be higher than 60 % in order to reach the suggested goal before year 2015. Some activities were identified to be important sub-goals to reach the targets and were given a proposed time limit:

> 2015 should 10 % of private wastewater outlets have solutions in which nutrients are recycled
> 2008 should at least three different phosphorus recovery systems be tested in full-scale
> 2008 should at least half of the municipalities have accepted strategies for recovery of nutrients in the wastewater (such as wastewater management plans) (Naturvårdsverket, 2000a)

The Swedish Environmental Protection Agency has proposed that a rule should be introduced in the Swedish law on water and sewerage (VA-lagen), that in principle implies an obligation to recover nutrients in a wastewater system and that the costs for the recovery may be regarded as a necessary cost. It is also stated by the Swedish Environmental Protection Agency that Sweden should act internationally to emphasize the role of phosphorus as a resource and it should be considered if Sweden should act in a way that a tax or fee is introduced on phosphorus use within EU (Naturvårdsverket, 2000a).

The intermediate target that by 2015, at least 60 per cent of the phosphorus in wastewater shall be restored to productive soil is at present sent for consideration to many organizations and the responses will be evaluated until decisions are made by the government. A lot of controversies exist concerning the target. In an early version of the report, referred to different organizations for consideration, proposed targets were as low as recycling to agricultural land with 25-30 % before 2015 and with 35-50 % before 2025. These low proposed requirements had a negative effect on the development of processes as KREPRO and BioCon for phosphorus recovery and further developments of these processes are at present uncertain. Earlier preliminary intentions that KREPRO should be built in the city of Malmö and the BioCon-system (using ion exchange) in the city of Falun are at present abandoned. It is therefore a need to reconsider the targets proposed by the Swedish Environmental Protection Agency and to evaluate if systems like KREPRO and

BioCon can be modified and if other technologies are more suitable related to efficiency, sustainability and costs.

Sweden seems to be the first country to propose a goal to recover phosphorus. Recently, the environmental authority of Åland (an autonomous province of Finland) has proposed a goal of 50 % recovery of phosphorus from sewage (Miljöbyrån, 2002). The phosphate industry has also shown interest to put up goals to recover phosphorus. Thus, the Western European phosphate industry has set up as a goal to reuse 25% of the recovered phosphate as raw material within a decade (Fielding, 2000). In the Netherlands two wastewater treatment plants with operating with the PhoStrip process supply the thermal phosphate industry Thermphos in Vlissingen with precipitated calcium phosphates.

METHODS AND STRATEGIES FOR PHOSPHORUS SAVING AND RECOVERY

Related to phosphorus savings and recovery many methods and strategies may be used in wastewater handling:

- Change of products containing phosphorus to substitute the phosphorus with other components (as phosphorus compounds in detergents, certain soft drinks and food products, corrosion inhibitors, etc)
- Sorting of waste streams inside households and buildings used for general purposes followed by separate handling of urine or toilet waste, which contain main part of the nutrients
- On-site treatment of rural wastewater not connected to municipal sewer systems by use of adsorption materials for phosphorus and where the material with adsorbed phosphate may be used as a fertilizer (Johansson, 1998)
- Use of effluent from a wastewater treatment plant for irrigation and where the effluent is used both for its water and nutrient contents
- Use of a certain sludge fraction (post-precipitated sludge, phosphorus enriched biological sludge, etc) as fertilizer or soil conditioner
- Separate treatment of nutrient rich side-streams obtained for instance from anaerobic treatment of phosphorus enriched sludge, supernatant from dewatering of digested sludge, and special treatment of sludge by heat, chemicals, etc.
- Production of a bio-soil in which sludge or a sludge fraction is a central part and for use on green areas (parks, road banks, golf courses, etc)
- Use of sludge as a raw material for production of products (including phosphorus products but also for energy production and for the building industry)
- Recovery of phosphorus and other products from incineration ash

SPECIAL EVALUATION OF SIX RE-USE TECHNOLOGIES OF PHOSPHORUS

Scientists within the research program “Sustainable Urban Water Management” together with additional researchers and consultants were requested by the Swedish EPA to provide a synthesis of current knowledge around potential systems for the re-use of phosphorus from sewage.

Six systems for the re-use were analyzed and compared with a reference system. The reference system was conventional wastewater treatment, including phosphorus and nitrogen removal, and incineration of sludge. The six systems were (Balmér et al., 2002):

- Separate collection of urine

Separate collection of blackwater
Direct agricultural use of dewatered and hygienised sludge
Extraction of phosphorus from wastewater
Extraction of phosphorus from sludge
Extraction of phosphorus from ashes after incineration of sludge

Incineration of sludge was included in all systems, except for the system with direct agricultural use of sludge. There should not be any concern regarding hygienic quality of the re-used product (Balmér et al., 2002). For the extraction methods one example was chosen for wastewater, sludge and ash, respectively, which was considered to be representative and also was estimated to be close to full scale application. For wastewater, the system with PhoStrip was chosen which produces calcium phosphates as a product. The KREPRO process was taken as an example of extraction of phosphorus from sludge and ferric phosphate is obtained as the product. Extraction of phosphorus from ashes was evaluated according to the BioCon concept with the recovery of phosphorus in the form of phosphoric acid. It was accentuated in the report that the chosen technologies more should be seen as examples and that other alternatives exist. The use of supercritical oxidation, followed by alkaline leaching of the residue and calcium phosphates as products was mentioned as an interesting emerging alternative.

SUSTAINABILITY OF THE METHODS

Harremoës (1996) has described ways to come towards a sustainable society. For sludge handling the following interpretation may be made:

Society should use its resources in such a way that the society can continue its mode of operation without its resources;
Society should protect the environment against irreversible damage including protection of unique species and habitats.

Bridle and Skrypski-Mantele (2000) write that when they address life-cycle assessment criteria necessary for sustainability, only beneficial reuse sludge options can be considered. It was suggested that four major criteria should be considered when evaluating the long-term sustainability of sludge reuse options:

Environmental/health protection
Resource recovery
Recovered versus invested resources
Beneficial versus total impact

In evaluation of the six re-use technologies for phosphorus calculations were made concerning (Balmér et al., 2002):

Potential recycling of nutrients (% from wastewater) for phosphorus, nitrogen, potassium and sulphur. It was estimated a 40% return of phosphorus for the system with separate collection of urine, 75% with collection of blackwater, 95% with direct sludge use, 60% with extraction from sewage, 70% with extraction of sewage sludge and 60% with extraction from ashes after incineration of sludge. Since 16% of the population live outside

urban areas, the total recirculation will be lower, although separate collection of urine and blackwater could also be introduced outside of urban areas.
Assumed losses in spreading and degree of plant availability
Emissions from the systems
Energy use
Index for weighting of consumption of phosphorus, potassium, sulphur, oil and natural gas

COST ESTIMATIONS

The average cost per person in Sweden for services of potable water and sewage is presently about 2000 SEK. Approximate costs for the studied systems in the report by Balmér et al. (2002) are:

Introduction of incineration (reference alternative) 50-100 SEK per person and year
Source separating systems 550 - 900 SEK per person and day
Direct use of sludge results in a decrease of 26 SEK compared with the reference alternative due to that incineration is not needed
Extraction of phosphorus from wastewater 14 SEK per person and day
Extraction of phosphorus from ashes and sludge 26-42 SEK per person and day

The cost estimations are much dependent on local conditions and should be seen as indications of costs and the relative cost for the different technologies and the relative cost compared with the total costs for potable water and sewage.

DISCUSSION

The costs for phosphorus recovery may be looked upon from many aspects. If, for instance, the cost for recovery of 60% phosphorus is 20 SEK (compared with the reference alternative), phosphorus recovery would increase the total costs for total services of potable water and sewage by 1%. With a specific load of phosphorus per person and day of 2.5 g P (annual load per person about 0.9 kg P) the cost per recovered phosphorus is about 22 SEK/kg P and higher than the market price for phosphorus of about 10 SEK/kg P. It is seen that even the most cost-effective systems at present for phosphorus recovery cannot be motivated based on possible revenues due to sale of phosphorus. In order to imply phosphorus recovery, different actions must be introduced as development of more cost-effective strategies and technologies for phosphorus recovery, legal and regulatory requirements, and "green" taxes on phosphorus use and discharges. Difficulties to use traditional disposal methods (disposal to sea is normally forbidden, possibilities to use landfills are increasingly more restricted or forbidden, difficulties for spreading on agricultural land, incineration ashes may be regarded as hazardous waste, etc.) may increase the different ways to use sludge as a resource in other ways than in agriculture. Phosphorus recovery has many side-effects – both positive and negative – that influence the economy. These effects include changes in sludge amount and dewatering properties, solubilisation of many sludge components, and possibilities to recover other products. Economical evaluation of phosphorus strategies and technologies is therefore very complex and needs further studies.

The efficiency of phosphorus reuse by spreading of sludge on agricultural land and its low cost makes this alternative interesting to further improve or modify. Several factors limit the use of sludge on agricultural land, including too high concentration of pollutants, restrictions of how much sludge that can be spread per ha, lack of agricultural land at near distance, and lack of acceptance from the public, farmers and different interest organizations. In Switzerland the authorities have proposed a ban on the use of biosolids in agricultural applications by 2005 (WE&T, 2002) and the environment minister Ulrich Müller in Baden Württemberg has recommended that all sludge should be incinerated rather than spread on farmland (Environment Daily, 2002).

A way to facilitate the use of sludge on farmland may be to sort the sludge in two fractions, one with a low ratio of phosphorus to pollutants (for instance sludge from pre-sedimentation) and one fraction with a high ratio of phosphorus to pollutants (for instance phosphorus enriched biological sludge and post-precipitated sludge). The first fraction could be treated in the traditional way with or without further treatment for phosphorus recovery. The second fraction could be used in agriculture after complementary hygienisation or be used as a central part in soil production. Improved metal removal in the pre-sedimentation basin would improve the sludge quality of secondary and tertiary sludges.

Instead of spreading the sludge on farmland, the sludge could be used on green areas such as road banks, parks and golf courses. Also in these cases sludge should have a high quality (similar to that for spreading on farmland). Direct use of a certain sludge fraction or use of sludge or a sludge fraction in production of “bio-soil” could facilitate the final disposal of the sludge (or part of the sludge).

There still exists economical and technical problems related to phosphorus recovery from sludge and ash by use of methods as KREPRO and BioCon, respectively. These methods were intended to be built in full-scale in the city of Malmö (KREPRO) and Falun (BioCon), but these plans have been postponed or abandoned. However, the methods might be improved or modified to be more cost-effective. A substantial release occurs of easily biodegradable organic materials that may be used to accomplish biological phosphorus removal and in that case much less chemicals are needed for the combined phosphorus removal and recovery. The BioCon process uses ion exchange technology to recover phosphorus from ash. Other ways to recover phosphorus from incineration of sewage sludge in the city of Falun will soon be started, for instance leaching of the ash by acids or bases.

Supercritical water oxidation followed by recovery from the formed rest product is a promising method, although the method needs to be further evaluated. Alkaline leaching followed by lime addition for formation of calcium phosphate has the potential to be accomplished with a low dosage of chemicals.

Side-stream technology by use of PhoStrip seems to be cost-effective in comparison with the other methods for phosphorus recovery except direct sludge use. The side-stream technology may be performed in many ways (Levlin and Hultman, 2003). Phosphate rich streams from a PhoStrip plant may be combined with nutrient rich streams from dewatering of digested sludge. In this case a suitable product for phosphorus recovery may be magnesium ammonium phosphate.

The methods studied in the report from Balmér et al. (2002) are evaluated based on that only one method is used. It is possible that different combinations may be advantageous such as use of certain “clean” sludge fractions in combination with extraction methods for phosphorus recovery or the use of side-stream technologies in combination with extraction methods of sludge or ash.

CONCLUSIONS

Sweden seems to be the first country to propose that phosphorus should be recovered from wastewater. A target has been set up of 60 % recovery (on a national basis) before 2015. A study at the Swedish Environment Protection Agency evaluated (1) separate collection of urine, (2) separate collection of blackwater, (3) direct agricultural use of dewatered and hygienised sludge, (4) extraction of phosphorus from wastewater (PhoStrip), (5) extraction of phosphorus from sludge (KREPRO) and (6) extraction of phosphorus from ashes after incineration of sludge (BioCon). It was found:

The highest degree of recovery (about 95%) and the lowest cost was obtained for direct agricultural use

Extraction of phosphorus from wastewater (use of PhoStrip) can recycle about 60% of the phosphorus and gives a cost of about 14 SEK per person and day

Extraction of phosphorus from sludge (KREPRO) or ash (BioCon) may recover about 60-70% and with a cost 26-42 SEK per person and day

Source separating systems may involve such high costs as 550-900 SEK per person and day

Some suggestions are given to improve and extend the possibilities for phosphorus recovery:

Use of sorted sludge fractions (such as biological sludge with an enhanced phosphorus concentration or post-precipitated sludge) with a high ratio of phosphorus to pollutants for spreading on farmland. The remaining sludge may be treated in a traditional way with or without phosphorus recovery.

Combined treatment of phosphate rich streams (for instance from PhoStrip) with nutrient rich streams from dewatering of digested sludge

Use of alkaline leaching of the rest product from supercritical water oxidation

Combined use of biological phosphorus removal and the KREPRO process

Two-stage phosphorus recovery by use of side-stream treatment followed by phosphate extraction from sludge or ash

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Appendix

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