Effects of phosphorus recovery requirements on Swedish sludge management

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Abstract Expected requirements of phosphorus recovery, restrictions on sludge disposal on landfill, and difficulties in obtaining consensus on sludge use on agricultural land has led to several development works in Sweden to change sludge management methods. Especially sludge fractionation has gained interest including following steps to recover products and separate transfer of toxic substances into a small stream. Commercial systems are offered based on technology by Cambi/KREPRO and BioCon and other companies and many other methods are under development. Iron salts are widely used in Sweden as precipitation agents for phosphorus removal and this technology has some disadvantages for phosphorus recovery compared with the use of biological phosphorus removal. The amount of chemicals needed for a KREPRO or a BioCon system was calculated for a treatment plant which has an addition of iron salt resulting in 1,900 mole Fe per tonne DS. The result was compared with the chemical consumption of recovery systems installed at plants with lower use of iron for precipitation. The chemical consumption in equivalents per tonne DS was found to be 5,000 + 6,000 ∗ (molar ratio iron to phosphorus).

Keywords Phosphorus recovery; sludge handling; Sweden

Introduction

New goals for phosphorus recovery

A national goal has recently been proposed in a report to the Swedish government that at least 75% of phosphorus from wastewater should be recovered at the latest by 2010 without risks for health and environment (Wallgren, 2001). The Western Europe phosphate industry has fixed an objective of using 25% recovered phosphates within a decade. Although both Swedish environmental authorities (SEPA) and the Western Europe phosphate industry seem to consider agricultural application of biosolids (sewage, sludges and manure) as the most ecological way to recover phosphorus other methods of recycling must be considered due to reasons of social acceptance, soil nutrient saturation or contamination issues.

Sweden has at present very stringent rules concerning limiting values of metal concentrations in sludge and they have gradually been strengthened. In addition there are guidance values on the maximum concentrations of indicator organic materials (nonylphenol, toluene, total PAH and total PCB). 49% of the reported sludge has some pollutant exceeding the permitted limit. Without consideration of toluene, 35% of the reported sludges exceeded the permitted limits. Looking only at the metal (Pb, Cd, Cu, Cr, Hg, Ni, Zn) content 23% of the reported sludges exceeded the permitted limits. A challenge for research and development works is, thus, to find new ways of phosphorus recovery (Levlin and Kapilashrami, 2000).

In general, phosphorus removal at a central wastewater treatment plant is obtained by use of excess phosphorus removal by biological means or by chemical precipitation. Most work on phosphorus recovery is based on wastewater treatment systems with biological phosphorus removal or precipitation of calcium phosphates in the main stream (Hultman et al., 2000). In Sweden, however, chemical precipitation by use of iron salts is the most used
method for phosphorus removal. Iron salts give a very efficient phosphorus removal due to a low solubility constant. However, phosphate binds to iron and ferric phosphate is not used as a raw material in the fertilizer industry, which prefers calcium phosphate from which phosphate can be more easily recovered.

**Present systems for phosphorus recovery**

Two systems for phosphorus recovery in wastewater treatment plants with chemical precipitation with iron salts is at present considered in Sweden for full scale applications: modified Cambi/KREPRO (Figure 1) and BioCon (Figure 2). The two systems have the general disadvantage that the iron content in the sludge is dissolved (by sulphuric acid) together with the phosphate. After dissolving the leachate contains a mixture of ferric and phosphate ions, which must be separated in a further step, either being precipitated as ferric phosphate (Cambi/KREPRO) or recovered as phosphoric acid by use of ion exchange (BioCon). In the BioCon-process, the iron ions are separated with a cation exchanger, which is regenerated with hydrochloric acid, giving ferric chloride as a product. Besides the need of chemicals for dissolving, an equal amount is needed for the precipitation or for regeneration of the ion exchangers. In leaching with acids heavy metals are also dissolved (Levin et al., 2000), which must be separated from phosphorus.

A comparison between Cambi/KREPRO and Bio-Con is shown in Table 1 and Swedish cities considering phosphorus recovery are shown in Table 2.

Recently two Swedish companies, Chematur and Feralco, have agreed to co-operate on phosphorus recovery. The system consists of supercritical water oxidation of digested sludge followed by leaching of the residues by acids or bases. The technology is called the AquaReci process and the oxidation process has been described by Gidner et al. (2000). The oxidation occurs in water of a supercritical phase at a temperature above 374°C and a pressure higher than 22 Mpa. Preliminary leaching tests at the Division of Water Resources Engineering, KTH, indicate that the phosphorus in the residue from the water oxidation process is easier to dissolve by acids than phosphorus in ashes from incineration.

![Figure 1](https://iwaponline.com/wst/article-pdf/46/4-5/435/426230/435.pdf)  
**Figure 1** Thermal hydrolyses with KREPRO (Hansen et al., 2000)
Chemical needs for phosphorus recovery

Table 3 shows a comparison of the need of chemicals for a plant with the BioCon system in Brønderslev, Denmark, and a plant with the KREPRO system in Helsingborg, Sweden. The amount of acids and alkali is expressed in equivalents (mole acid or alkali times ion valency) per tonne DS (dry solids) since the amount of dissolved ferric phosphate depends on the amount of acid in equivalents. In the Brønderslev treatment plant, sludge from...
biological phosphorus removal is incinerated without digestion and the iron content is 200 moles per tonne DS. At sludge digestion trivalent iron is converted to divalent and biologically bound phosphorus is released and therefore a higher addition of iron must be used to bind phosphorus to the sludge and avoid a return flow of phosphorus with the supernatant. This means that an excess of iron is needed to avoid release of phosphorus in the digester, which will return with the supernatant to the treatment plant. The treatment plant in Helsingborg is partly equipped with biological phosphorus removal and the sludge has an iron content of 700 moles per tonne DS. Table 3 shows that the KREPRO-plant at Helsingborg with a higher iron salt addition has a higher consumption of chemicals than the BioCon-plant at Brønderslev.

Calculations of chemical needs for Henriksdal WWTP
The general principal for recovering phosphorus from sewage sludge includes first a release step of phosphorus from the sewage sludge followed by precipitation to a phosphorus product. A calculation model has been developed (Hultman et al., 2001; Stark et al., 2001) to estimate the chemical demand of acids and bases to transfer the particle bound phosphorus to a liquid phase followed by product recovery. Table 4 shows a calculation of the amount of chemicals needed for a KREPRO and a BioCon system for the Henriksdal treatment plant in Stockholm, which operates with an addition of iron salt resulting in 1900 mole Fe per tonne DS.

Chemical needs as a function of iron content
The calculated consumption for Henriksdals treatment plant in Stockholm can be compared with the total chemical consumption of the plants in Brønderslev, Denmark and

Table 3  Comparison of needs of acid and alkali chemicals per tonne DS (dry solids) for BioCon and KREPRO (equivalents, eq. = mole × ion valency)

<table>
<thead>
<tr>
<th>System</th>
<th>eq./tonne DS</th>
</tr>
</thead>
<tbody>
<tr>
<td>BioCon (Brønderslev, Denmark)</td>
<td></td>
</tr>
<tr>
<td>Consumption from application for permit (Svensson, 2000)</td>
<td></td>
</tr>
<tr>
<td>Dissolution of ash with 2983 eq. (146 kg) H₂SO₄ (192 kg reduced with 46 kg for release of phosphoric acid from the ion exchanger)</td>
<td>2983</td>
</tr>
<tr>
<td>Recovery with 723 eq. (26 kg) HCl, 1225 eq. (49 kg) NaOH and 939 eq. (46 kg) H₂SO₄</td>
<td>2887</td>
</tr>
<tr>
<td>Sum</td>
<td>5870</td>
</tr>
<tr>
<td>KREPRO (Öresundsverket Helsingborg, Sweden)</td>
<td></td>
</tr>
<tr>
<td>Consumption at operation (Hansen et al., 2000)</td>
<td></td>
</tr>
<tr>
<td>Dissolution of sludge with 4082 eq. (200 kg) H₂SO₄ (theoretically calculated need is 2135 + 2390 = 4525)</td>
<td>4082</td>
</tr>
<tr>
<td>Recovery with 5000 eq. (200 kg) NaOH and 411 eq. (12 kg) Mg(OH)₂ (Additional need is 2 kg polymers, 93 kg FeCl₃ and 463 kWh energy)</td>
<td>5411</td>
</tr>
<tr>
<td>Sum</td>
<td>9493</td>
</tr>
</tbody>
</table>

Table 4  Comparison of calculated needs of acid and alkali chemicals per tonne DS (dry solids), for a BioCon and a KREPRO system, respectively, at Henriksdals treatment plant in Stockholm (equivalents, eq. = mole × ion valency)

<table>
<thead>
<tr>
<th>System</th>
<th>eq./tonne DS</th>
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</thead>
<tbody>
<tr>
<td>BioCon</td>
<td></td>
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<tr>
<td>Dissolution of ash with 9714 eq. (475 kg) H₂SO₄</td>
<td>9714</td>
</tr>
<tr>
<td>Recovery with 7397 eq. (286 kg) HCl, 1225 eq. (49 kg) NaOH and 1040 eq. (51 kg) H₂SO₄</td>
<td>9662</td>
</tr>
<tr>
<td>Sum</td>
<td>19376</td>
</tr>
<tr>
<td>KREPRO</td>
<td></td>
</tr>
<tr>
<td>Dissolution of sludge with 7551 eq. (370 kg) H₂SO₄</td>
<td>7551</td>
</tr>
<tr>
<td>Recovery with 7600 eq. (304 kg) NaOH</td>
<td>7600</td>
</tr>
<tr>
<td>Sum</td>
<td>15151</td>
</tr>
</tbody>
</table>
Helsingborg, Sweden, (Table 3). The phosphorus content in the sludge was assumed to be 1000 mole per tonne DS (3.1%), which gives the molar ratio of iron to phosphorus to be; BioCon at Brønderslev, mole Fe/mole P = 0.2, KREPRO Helsingborg, mole Fe/mole P = 0.7, and Henriksdal, mole Fe/mole P = 1.9. The chemical consumption was found to be a function of the molar ratio of iron and phosphorus in the sludge:

\[ K_e = 5000 + 6000 \times \frac{F_m}{P_m} \]

where: \( K_e \) = chemical consumption in equivalents per tonne DS; \( F_m \) = mole Fe in the sludge per tonne DS; \( P_m \) = mole P in the sludge per tonne DS.

**Discussion**

Sweden has a long tradition of using chemical precipitation for phosphorus removal. Introduction of phosphorus recovery may strongly affect future strategies for operation of treatment plants with both requirements of phosphorus removal and recovery. The stringent phosphorus removal requirements (for larger plants normally 0.3 mg total P/l as quarterly average value) make it difficult to only use biological phosphorus removal. This means that part of the phosphorus in the sludge will be chemically bound and will not be released under anaerobic conditions as for sludges with enhanced biological phosphorus removal.

A special difficulty in phosphorus recovery is the possible refixation of released phosphorus in the digester due to chemical precipitation or adsorption (Jardin and Pöpel, 2001). This problem may be avoided if the excess sludge will be treated in a separate anaerobic step where the sludge will not come in contact with, for instance, pre-sedimentated sludge or post-precipitated sludge.

Another problem is lack of easily bio-degradable organic material to accomplish enhanced biological phosphorus removal. This is, for instance, the case for the two largest wastewater treatment plants in the Stockholm region. Substances such as acetic acid are expensive and therefore internal production of organic acids seems to be necessary based on operational costs. This production may be done by use of anaerobic fermentation of primary sludge, thermal treatment of sludges or chemical hydrolysis by addition of, for instance, sodium hydroxide.

Problems related to large amounts of chemicals needed in recovery of phosphorus from chemical sludges, possible refixation of phosphate in digesters and lack of influent organic acids have led to recommendations to consider the following operational strategies (Stark et al., 2001):

- Changes of chemical precipitation to enhanced biological phosphorus removal in the activated sludge process
- Release of phosphate from excess sludge in a separate anaerobic step (cf Giesen, 1999 and Klapwijk et al., 2001)
- Separate internal production of organic acids
- Separate treatment of chemically bounded phosphorus

Phosphorus recovery is then performed in two steps, one for phosphorus mainly bound biologically and one for phosphorus mainly bound chemically. The different systems: Cambi/KREPRO, BioCon and Chematur/Feralco can recover chemically bound phosphorus while different systems based on biological phosphorus may be used to recover part of the phosphorus in a less chemical consuming way.

Savings in chemicals may also be obtained if chemically bound phosphorus is released in a selective way. Selective release of phosphate from precipitates can be achieved by use of sulphides (Ripl et al., 1988). At a high pH-value aluminium and iron are converted to metal hydroxide thus dissolving the phosphate (Stumm and Morgan, 1981):

\[ \text{MePO}_4 (s) + 3 \text{OH}^- \rightarrow \text{Me(OH)}_3 (s) + \text{PO}_4^{3-} \]
Conclusions

Requirements for both phosphorus removal and recovery have recently been proposed in Sweden. This may lead to substantial changes in operation of municipal wastewater treatment plants. Recovery by combined thermal and acid sludge treatment leads to high needs for chemicals and is a linear function of the molar ratio of iron and phosphorus in the sludge. The necessary amount of equivalents of acids and bases in the Cambi/Krepro and BioCon systems is approximately:

\[ K_e \text{ (equivalents/tonne DS)} = 5000 + 6000 \times \frac{Fe_m}{P_m} \]

The need for chemicals is mainly dependent on sludge composition and to a much less extent on the chosen process technology by Cambi/Krepro and BioCon, respectively. Ways to reduce costs for phosphorus recovery include changes from chemical precipitation to enhanced biological phosphorus removal, internal production of organic acids, selective removal of chemically bound phosphorus and recovery of biologically and chemically bound phosphorus in two separate stages.

Acknowledgement

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References


