Dutch analysis for P-recovery from municipal wastewater

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Abstract

There is a considerable practical interest in phosphorus recovery from water authorities, elementary P-industry, fertilizer industry and regulators in a number of countries. Due to a handful of full-scale plants worldwide, P-recovery can be seen as technically feasible. However, the economic feasibility of P-recovery from sewage can still be judged as dubious. The most important reason for this is that the prices of the techniques (in €/tonne P) are much higher compared to the prices of phosphate rock. In this paper an analysis is given to recover phosphate from municipal wastewater for the elementary P-industry Thermphos International B.V. and the fertiliser industry Amsterdam Fertilizers B.V. in The Netherlands. Several scenarios are evaluated and the end products of these scenarios are compared to the quality required by both industries. 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. As a consequence of this, the most preferred possibility for P-recovery is to extract phosphate before sludge goes to the final sludge treatment. Different scenarios can be selected based on the position of P-recovery in the WWTP configuration, the type of P-recovery product, and the precipitation technique. Local conditions will determine which scenario is the most expedient. Because it is more realistic to judge a practical situation instead of theoretical estimations based on literature, some local situations have to be assessed in sufficient detail to gain more feeling for the expenses and possible savings of P-recovery. One important actor that should be involved in the process management around P-recovery, is the national government. Especially, the Government have the responsibility for sustainable development and should have attention for some stimulation of P-recovery in The Netherlands. Water authorities and the P- and fertilizer industry made already some good steps.

Keywords Costs; phosphate recovery; sludge treatment; wastewater

Introduction

During the Second International Conference on the recovery of phosphorus from sewage and animal wastes (CEEP, 2001), it was concluded that there is a considerable practical interest in P-recovery from both water companies and regulators in a number of countries. Over 260 participants were present in Noordwijkerhout, The Netherlands in March 2001. This was around twice the attendance at the first meeting three years previously in Warwick in the UK.

By a handful of full-scale plants already operational in Italy, Japan, The Netherlands and Sweden, it is shown that P-recovery is technically feasible. In spite of that, the economic feasibility of P-recovery from sewage can still be judged as dubious. The most important reason for this is that the prices of the techniques (in €/tonne P) are much higher compared to the prices of phosphate rock. Although economic viability is usually the main driver, the authors list many advantages that are related to the implementation of P-recovery (e.g. Jeanmaire, 2001). Some of these can also be used in determining the economic feasibility. An important technological advantage is that less phosphate will be returned from the sludge treatment facilities such as thickeners and digesters, resulting in a better P-removal efficiency (Wild et al., 1997). At the same time, the problem of undesired P-precipitation in the form of struvite can be diminished (Jaffer et al., 2001). P-recovery also will allow a decrease of the costs for treatment and disposal of sludge, because it results in a reduction of...
2–6% sludge at dry solid base and 12–48% based on incineration ash (Etienne et al., 2001). Finally, sludge with a lower P-content may have a better application as a secondary material, for instance in the cement industry (Klapwijk and Temmink, 2004).

When there is no direct economic driver, regulations can be a stimulating factor. Sweden is a country that adopted a policy where a national target of recovering and recycling 75% of phosphorus from sewage has been set. In order to move towards this target, Sweden now requires P-recovery to be installed as one condition for authorisation for sewage sludge incineration plants.

Also the phosphorus industry can have an aim for sustainable development. In order to reduce the consumption of phosphate rock and to close the phosphorus cycle, Thermphos International B.V. from The Netherlands has stated the objective of replacing 20% of its current phosphate rock consumption by recovered phosphates.

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In this paper the possibilities to recover phosphate from municipal wastewater for the elementary P-industry Thermphos International B.V. and the fertiliser industry Amsterdam Fertilizers B.V. will be reviewed. Several scenarios are evaluated and the end products of these scenarios are compared to the quality required by both industries (Table 1).

In general two possibilities to recover P from municipal wastewater can be distinguished. The first is to use the end product of the sludge treatment. The second is to extract and precipitate phosphate from sludge before it is treated, and to use the precipitate as a secondary source of phosphate. For the second possibility, bio-P removal is often stated as the prerequisite for a successful P-recovery.

For the analysis on P-recovery, it is important to mention that already since 1995 agricultural spreading of sewage sludge in The Netherlands is no longer an option. The produced sludge at the WWTPs is transported to the sludge processors after it has been thickened and dewatered. At present there is in The Netherlands sufficient treatment capacity for the produced sewage sludge. Table 2 presents the diversity of sludge processes in The Netherlands and from here it can be seen that incineration is by far the most used sludge treatment process.

Analysis of the Thermphos case

Thermphos International B.V. produces and sells different phosphorus products. Therefore Thermphos imports 600,000 tons of phosphate ore per year from North Africa and Russia (equivalent to 200,000 tons of P₂O₅). The objective of Thermphos by replacing 20%

Table 1 Requirements for products of P-recovery at Thermphos International B.V. (STOWA, 2001) and Amsterdam Fertilizers B.V. (Langeveld, 2003)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Thermphos elementary P-industry</th>
<th>Amfert fertilizer industry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry mass</td>
<td>(%)</td>
<td>&gt; 75</td>
<td>&gt; 90</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>(% of DS)</td>
<td>&gt; 18</td>
<td>&gt; 18</td>
</tr>
<tr>
<td>Fe</td>
<td>(mg/kg)</td>
<td>&lt; 10,000¹)</td>
<td>No set requirement</td>
</tr>
<tr>
<td>Zn</td>
<td>(mg/kg)</td>
<td>&lt; 100²)</td>
<td>530</td>
</tr>
<tr>
<td>Cu</td>
<td>(mg/kg)</td>
<td>&lt; 10³)</td>
<td>220</td>
</tr>
<tr>
<td>Hg</td>
<td>(mg/kg)</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>As</td>
<td>(mg/kg)</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>Cd</td>
<td>(mg/kg)</td>
<td>14</td>
<td></td>
</tr>
<tr>
<td>Cr/Ni/Pb</td>
<td>(mg/kg)</td>
<td>170</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>–</td>
<td>Not present</td>
<td>No set requirement</td>
</tr>
</tbody>
</table>

¹) Calculated to 40,000 tonnes P₂O₅ (in mg/kg DS) and a maximum accepted load of 2,000 tonne/year
²) Calculated to 40,000 tonnes P₂O₅ (in mg/kg DS) and a maximum accepted load of 20 tonne/year
³) Calculated to 40,000 tonnes P₂O₅ (in mg/kg DS) and a maximum accepted load of 2 tonne/year
(40,000 tons of $P_2O_5$) of its current phosphate rock consumption by recovered phosphates, initiated a study in The Netherlands with a focus on the quality and quantity of available phosphates in recovered materials from sewage treatment plants and sewage sludge processors (STOWA, 2001). Based on defined quality criteria, the current and future technical feasibility of using these recovered phosphates as a raw material for the phosphorus production process of Thermphos was assessed. The most important requirements they set for the P-product are given in Table 1. The DS-requirement is based on the possibilities of granulation and the internal water management. Too high iron, zinc and copper concentrations will lead to problems in the deposition of the rest product.

Based on dry mass and $P_2O_5$ value, the rest product from incineration is the most suitable for P-recovery. However, the Fe, Cu and Zn content of the ashes are much higher than the requirements and therefore Thermphos cannot use this end product. The most used metal for chemical phosphorus removal is iron and due to that, the Fe content of the ashes is too high. This bottleneck could be solved by a wide application of aluminium as metal salt or by implementing biological phosphorus removal. With both measures it can be expected that the contents of Zn and Cu will be in the same range as for the situation as presented in Table 3. In general it is concluded that ash from incinerated sludge does not provide a good source of secondary phosphates for Thermphos. Because the ashes are so polluted with heavy metals, ashes are difficult to reprocess to a suitable P-recovery product.

Another option for P-recovery is to extract and precipitate phosphate from sludge before it is treated. Processes that precipitate phosphate as relatively pure product from liquid streams within the WWTP, can produce materials that are eminently suitable for reuse in the phosphorus production process. Practical experience with the Crystalactor® at the Geestmerambacht WWTP in The Netherlands shows that a suitable recovered material (calcium phosphate) can be obtained which poses none of the mentioned problems. At the moment Thermphos is using the total output from this reactor. The agreement with Thermphos is that they collect the recovered phosphates from the WWTP on a no cost–no payment basis.

Phosphate precipitation processes are most likely to be installed at WWTPs with biological phosphorus removal, as these offer side streams with high phosphate concentrations. An inventory was made of plants in Holland already operating a biological

### Table 2 Mass of sludge treated in The Netherlands

<table>
<thead>
<tr>
<th>Sludge treatment</th>
<th>Sludge (ktonne DS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>347</td>
</tr>
<tr>
<td>Incineration</td>
<td>220</td>
</tr>
<tr>
<td>Thermal drying</td>
<td>82</td>
</tr>
<tr>
<td>Composting</td>
<td>31</td>
</tr>
<tr>
<td>Wet oxidation</td>
<td>10</td>
</tr>
<tr>
<td>Other</td>
<td>4</td>
</tr>
</tbody>
</table>

### Table 3 Rest products of sludge treatment processes in comparison with Thermphos requirements

<table>
<thead>
<tr>
<th>Sludge treatment</th>
<th>Sludge (kton DS)</th>
<th>Dry mass (%)</th>
<th>$P_2O_5$ (%) of DS</th>
<th>Fe (mg/kg)</th>
<th>Zn (mg/kg)</th>
<th>Cu (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incineration</td>
<td>220</td>
<td>100</td>
<td>$\pm$ 15-17</td>
<td>80,000</td>
<td>1,800</td>
<td>1,100</td>
</tr>
<tr>
<td>Thermal drying</td>
<td>82</td>
<td>90</td>
<td>$\pm$ 7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Composting</td>
<td>31</td>
<td>65</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wet oxidation</td>
<td>10</td>
<td>50</td>
<td>–</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermphos requirement</td>
<td>&gt; 75</td>
<td>&gt; 18</td>
<td>&lt; 10,000</td>
<td>&lt; 100</td>
<td>&lt; 10</td>
<td></td>
</tr>
</tbody>
</table>
phosphorus removal stage, and plants susceptible to be adapted for biological phosphorus removal. On this basis, it was estimated that phosphate precipitation reactors could generate a stream of recovered phosphates that would cover circa 5% of the total phosphate requirement of Thermphos.

Except for the P-recovery at Geestmerambacht, no further developments in The Netherlands can be reported at sewage treatment works. Thermphos determines the quality of the product that must be reached and they claim that the recyclable product must be calcium phosphate or aluminium phosphate and not struvite. As a consequence of this situation, the most preferred possibility for P-recovery is to extract phosphate before sludge goes to the final sludge treatment.

**Possibilities for P-recovery at Amfert**
Amsterdam Fertilizers B.V. (Amfert) was acquired in September 1982 by Israel Chemicals Limited (ICL) as part of ICL’s policy to enlarge its share in the West European market. In contrast with other Western European producers that focus on nitrogen, Amfert in Amsterdam is together with the unit in Ludwigshafen, mainly focused on fertilizers with phosphorus and potassium. These two units import together 350,000 tons of phosphate ore, which is similar to approximately 110,000 tons of P₂O₅. Although they don’t have a policy for reusing P recovered products from sewage like Thermphos, they are in principle interested in the possibility. A constraint is that Amfert does not want to be seen as a waste manager.

The requirements for P-recovery products at Amfert are shown in Table 1. These requirements are based on their licence for the intake of products and do not mean that the values are absolute maximums. It might be possible to acquire a new licence that approves of higher concentrations. In comparison with the requirements of Thermphos, Langeveld (2003) indicates that products with Ca, Fe, Al, Mg and nitrogen do not negatively influence the production process of Amfert in Amsterdam. This means that besides calcium- and aluminium phosphate, also iron phosphate and struvite can be recycled at Amfert. Heavy metals such as Cu and Zn can even be used as trace elements in the fertilizer product. More problems are expected with the concentrations of Pb and Hg in the P-recovery product. The requirement for the dry mass content is 90% higher for the Amfert case. Although most of the requirements are less strict, also for Amfert the most preferred possibility for P-recovery is to extract phosphate before sludge goes to the sludge treatment.

**Possible scenarios for P-recovery**
**Scenarios for P-recovery at bio-P plants**
At a bio-P plant phosphate can be extracted at three locations (Figure 1). The first is the sludge originating from the anaerobic compartment, the second from the activated sludge mixture from the last aerobic compartment and the third in the sludge line after digestion and dewatering.

The first option has the advantage that phosphate is already available in soluble form. In this approach the excess sludge is not withdrawn from the settling tank but from the anaerobic compartment where phosphate is released with the wastewater as carbon source. The phosphate containing water has to be separated from the sludge in a thickener. The water phase goes to a precipitation reactor for the P-recovery. A disadvantage of this scenario is that precipitation has to take place at low phosphate concentrations (20–40 mg/l).

In the second scenario phosphate has to be released from the return sludge in an additional anaerobic compartment by adding a carbon source. This results in higher P-concentrations in the water phase than with the first option (60–80 mg/l). A disadvantage of this scenario is the higher cost for additional equipment and chemicals for the P-stripping unit.
Figure 1 Possible scenarios for P-recovery at WWTPs. (A) bio-P plant with phosphate extraction from sludge of the anaerobic compartment, (B) bio-P plant with phosphate extraction from sludge of the aerobic compartment and (C) bio-P plant with P-recovery in the sludge line.
When a digester is available, the third scenario can be applied. In this scenario the digester supernatant is treated after dewatering. High P-concentrations are present (> 100 mg/l) and there is no need for an additional carbon source. A disadvantage of this scenario is that a lower P-recovery can be obtained due to the fact that in the digester spontaneous precipitation of phosphorus takes place. In Germany, where many bio-P plants are equipped with a digester, less than 20% of the total influent P-load is returned via the digester supernatant (Jardin and Pöpel, 2001).

Full-scale experience with phosphate precipitation
After the phosphate has been extracted from the sludge, and the phosphate-rich water is separated from the sludge, the phosphate has to be precipitated. Already mentioned for the Thermphos case, a method that is applied in practice, is the Crystalactor® (Piekema and Giessen, 2001) where the phosphate is in a side-stream process converted into P-pellets with calcium. This P-recovery product has a high quality and is used by Thermphos and can also be accepted by Amfert. However, this technique is at about €7,300 per ton removed P (Gaastra et al., 1998) quite costly.

Another possibility for phosphate precipitation is the formation of struvite. Three P-recovery units are operational at Shimane Prefecture Sewage Works in Japan, two of which have been in place since 1998 and one since 2000 (Ueno and Fujii, 2001). These units treat the digester supernatant after dewatering with a feed concentration of 100–110 mg/l P. The struvite is under addition of magnesium hydroxide and sodium hydroxide precipitated as pellets in a fluidised bed reactor. The struvite pellets contain hardly any toxic substances and the product is sold for €250/ton to fertilizer companies as a fertilizer raw material. A further economic analysis of this full-scale P-recovery in the form of struvite was not found in the literature.

For two other options of struvite precipitation (Jaffer et al., 2001 and Battistoni, 2001), Jeanmaire (2001) estimated costs of approximately €2,750 per ton removed P. A disadvantage of struvite is that Thermphos cannot use this in their process.

Other possibilities for P-precipitation
A simple precipitation with lime is cheaper than the Crystalactor®, but has as a disadvantage that a very fine precipitate is formed which is difficult to separate and dry (Temmink et al., 2002). Besides calcium phosphate, Thermphos (and also Amfert) can accept aluminium phosphates as a P-recovery product. Precipitation can take place with aluminium salts or poly-aluminium chloride (PAC). The estimated costs (including investment costs) for this possibility are €4,000 per ton removed P (Temmink et al., 2002). When aluminium is used, it can be expected that metals are co-precipitated. This last effect can also appear when iron is used as metal salt. For iron phosphates, Amfert indicates (Langeveld, 2003) that this can be accepted for their fertilizer production process.

Economic considerations of P-recovery
In the present situation, large-scale recovery of phosphorus from municipal wastewater is economically not feasible. The P-recovery product that is produced in case of the Crystallactor® at Geestmerambacht is at €7,300/ton P around 22 times more expensive than mined phosphate rock with a price for northern Europe of €320/ton of P (Jeanmaire, 2001). The present agreement with Thermphos is based on a no cost–no payment basis, and this means that the water authority is fully responsible for the costs of the Crystallactor®. By the implementation of some optimisations the costs could be reduced to €5,900, being still 18 times more expensive. Under these conditions this seems to be an unbridgeable difference for other water authorities. Nevertheless, an attempt is given in trying to lower this difference and to make P-recovery more attractive.
Selection of P-recovery scenario.
In the situation of Geestmerambacht, the side-stream process for biological P-removal is used (scenario B, Figure 1). The biological part of this scenario determines a significant part of the total costs. When a sludge digester is available, scenario C (Figure 1) can be selected. By implementing a struvite reactor, costs can be €2,750 per ton removed P (Jeanmaire, 2001). Compared with mined P-rock the costs via this scenario will be 9 times more expensive. Another option is the selection of scenario A (Figure 1) with a precipitation with ammonium. This results in a cost level that is still 12 times higher.

Reduction of the sludge production.
With the implementation of P-recovery at a WWTP, a sludge reduction of 2–6% can be obtained. It can be wondered if this reduction will be visible, due to the dynamic fluctuations in the sludge production and the inaccuracy in the determination of the sludge production. The average costs for sludge treatment in The Netherlands are approximately €450/ton dry mass. When the possibility for sludge reduction is taken into account in the economic analysis of P-recovery, this would mean a saving of €450/ton P. Assuming that the P-industry is not prepared to give a price for the P-recovery product, the costs are €2,750 for struvite and €4,000 for aluminium phosphate respectively 6 and 9 times higher than the savings.

Paying a price for the P-recovery product.
With the condition that the quality of the P-recovery product is according to the requirements of the P-industry, a price can be assumed that is comparable with the price for P-rock. The total benefits of P-recovery are then €770 and this would result in a cost level that is still 3.5 and 5 times higher for respectively struvite and aluminium phosphate. Chances to improve the feasibility are an increase in the price for phosphate rock or the selling of the P-recovery product on the local agricultural market for a price that is comparable with the market price for fertilizers.

Other savings due to P-recovery.
In the literature it is often found that with P-recovery savings can be reached due to the suppression of problems of struvite deposits. Till the present, only two WWTPs in The Netherlands reported such problems, and this means that this problem is not a big issue. Another saving could be on the landfill of incineration ashes. Most of these ashes are however usefully used in the mining industry or road construction.

The above-mentioned economic analysis is in fact over-simplified because every aspect has some differentiations and as a result of the many aspects involved in the economic analysis of P-recovery, it is also necessary to be aware of local conditions (e.g. the existing situation in the treatment plant, cost of sludge disposal processes, cost of the reagents used, cost of fertilizers, etc.). Nevertheless, in this way it is made clear that even with some significant steps in improving the economic feasibility of P-recovery, the Dutch water authorities still take the view that the expenses outweigh the benefits.

Future activities on P-recovery
For some years there was in The Netherlands a complete focus on the possibilities of P-recovery at Thermphos. The case of Geestmerambacht with the Crystallactor® is judged as economically poor. The only other possibility for P-recovery at Thermphos is the precipitation of aluminium phosphate. The recent interest of the fertilizer industry Amfert enlarges the options for P-recovery. First of all they can accept other products (iron phosphate and struvite) and secondly the requirements for most of the heavy metals are less strict than in the case of Thermphos.
At the Wageningen University (Temmink et al., 2002) research was carried out in the precipitation of phosphate with aluminium, according to scenario A (Figure 1). Precipitation experiments show that an end product can be obtained that is applicable for both Thermphos and Amfert. The same experiments also have to be performed for iron phosphate and struvite. These experiments will take place with bio-P sludge from a WWTP where at least bio-P is introduced and with digester supernatant. Amfert is interested in testing a few kilos of each product in their test facility. When the products are qualified as recyclable, further research has to be carried out into several aspects of the precipitation process and the possibilities for dewatering and drying the precipitate.

The determination of the economic feasibility of P-recovery is a complex issue. More feeling will be gained when for some local situations this is thoroughly investigated. Expenses and possible savings have to be judged objectively. An interesting aspect that needs further research is the question of the economic scale and the related question if P-recovery should be organised centrally or decentralized. The WWTPs in The Netherlands are scattered over the country and there are only a few treatment plants with a capacity higher than 500,000 p.e. In the last few years many water authorities organised their sludge dewatering and/or sludge digestion in a centralized way and this can offer opportunities in improving the economic feasibility of P-recovery.

Besides the water authorities, elementary P-industry and fertiliser industry, other actors can be involved in the discussion around the possibilities and the need for phosphorus recovery. One important actor is the national government. A positive example is found in Sweden where a policy has been set for a national target of recovering and recycling 75% of phosphorus from sewage. For The Netherlands it would be wise to organise a meeting with the above-mentioned actors. An important objective of this meeting should be to inform the national government about the possibilities, the hindrances and the responsibilities of all these actors concerning P-recovery.

Conclusions

An important step concerning P-recovery in The Netherlands was the stated objective of Thermphos to replace 20% of its current phosphate rock consumption by recovered phosphates. However, except for the already existing P-recovery with the Crystallactor® at Geestmerambacht, no further developments in The Netherlands could be initiated. The main reason for this is that the Dutch water authorities take the view that the expenses of P-recovery still outweigh the benefits. At Thermphos the possibilities are limited to calcium phosphate and aluminium phosphate. Since recently also the fertilizer industry Amfert has an interest in P-recovery, and due to that the possibilities in terms of end product are extended with struvite and iron phosphate.

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. As a consequence of this, the most preferred possibility for P-recovery is to extract phosphate before sludge goes to the final sludge treatment. Different scenarios can be selected based on the position of P-recovery in the WWTP configuration, the type of P-recovery product, and the precipitation technique. Local conditions will determine which scenario is the most expedient.

Because it is more realistic to judge a practical situation instead of theoretical estimations based on literature, some local situations have to be assessed in sufficient detail to gain more feeling for the expenses and possible savings of P-recovery. An interesting aspect that needs further research is the question if P-recovery should be organised centrally or decentralized. Besides the water authorities, Thermphos and Amfert must be directly involved for the creation of sufficient support.

One important actor that also should be involved in this process is the national
government. Especially they have the responsibility for a sustainable development and should have attention for some stimulation of P-recovery in The Netherlands. Water authorities and the P- and fertilizer industry have made already some good steps.

References


