Full scale optimisation of sludge dewatering and phosphate removal at Harnaschpolder wwtp (The Hague, NL)

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Abstract

At Harnaschpolder wwtp phosphate removal from wastewater and sludge dewatering is optimised by dosing magnesium hydroxide to digested sludge. To optimise sludge dewatering and phosphate removal, a full-scale test has been executed since August 2015 using temporary equipment. In this test magnesium hydroxide is added to the digested sludge buffer. Significant positive results are achieved. An excellent quality of the reject water is obtained, through which the phosphorus load in this reject water returned to head of works is negligible. This decrease in combination with other optimisations are beneficial for the biological phosphorus removal process. In 2016 the phosphorus effluent quality remained constant, while 42\% less iron chloride was added to meet the legal phosphorus effluent quality requirements (yearly moving average $P_{\text{total}} < 1.0$ mg P/l). The polymer usage decreased by 25\% and the year average dry matter content of the dewatered sludge increased from 22\% in 2014 to 24\% in 2016. Struvite scaling or blockage is avoided in piping, pumps or dewatering equipment, through optimised control of dosage of magnesium hydroxide. The full-scale test results prove that the addition of magnesium hydroxide to digested sludge leads to a significant cost reduction and major environmental benefits. In 2017 a permanent installation will be realised. The magnesium hydroxide dosage will be further optimised based on lessons learnt. Also an improved operation control of sludge dewatering is possible through additional in-line measurements for dry solids content of dewatered sludge. It is therefore expected that results will further improve concerning the use of iron chloride and polymers, dry solids content of dewatered sludge and phosphate effluent quality. Through this optimisation, the operating costs\textsuperscript{1} of Harnaschpolder wwtp are reduced by over 4\%. The return on investment is estimated at 1.5 years.

Key words: wastewater treatment, sludge dewatering, biological phosphate removal, phosphate recovery from wastewater

INTRODUCTION

At Harnaschpolder wwtp approximately 255,000 m$^3$ of wastewater is treated daily from 1 million inhabitants and thousands of companies in the region of The Hague. The capacity of Harnaschpolder wwtp amounts to 1.3 million population equivalents, which makes it the largest in the Netherlands (see Figure 1). The process consists of activated sludge treatment including primary settling, digestion and sludge dewatering. The dewatered sludge is handled by a dedicated sewage sludge incineration plant (HVC Dordrecht, NL), which is in use by five Dutch Water Authorities.

\footnote{Operating costs are all expenses related to the operation of the wwtp but do not include capital costs (depreciation).}
At Harnaschpolder wwtp phosphate is predominately biologically removed from the wastewater through luxury uptake by Phosphorus Accumulating Organisms (PAOs). These micro-organisms store phosphate within their cells under aerobic conditions as energy-rich polyphosphate granules, along with magnesium, calcium and potassium cations. Under anaerobic conditions, e.g. sludge digestion, polyphosphate and cations are released again. This release has negative side effects on the operation of the activated sludge and dewatering processes.

First of all the release of phosphate during digestion causes high phosphate concentrations in the reject water of the sludge dewatering. This reject water is returned to the head of works. This phosphorus feedback represents around 20% of the total phosphorus load to the activated sludge system (see Figure 2). To cope with this extra phosphorus load, additional iron chloride has to be added to meet the legal phosphorus effluent requirements (yearly moving average \( P_{\text{total}} < 1.0 \text{ mg P/l} \)).

![Figure 1 | Harnaschpolder wwtp.](image1)

![Figure 2 | Phosphorus mass balance Harnaschpolder wwtp. Red numbers are without and green numbers are with controlled struvite precipitation.](image2)
Secondly phosphate concentrations in incoming wastewater and digested sludge vary during rain water events opposed to dry weather conditions and also during seasons. This hinders a stable operation of the sludge dewatering, which causes a less dry solids content of the dewatered sludge despite frequent adjustment of control parameters like polymer use, flow and torque.

Finally high concentrations of phosphate, nitrogen and magnesium at pH-levels of ≥7 lead to uncontrolled precipitation of struvite (magnesium ammonium phosphate: \((\text{Mg(NH}_4\text{)}\text{PO}_4\cdot6\text{H}_2\text{O})\)). This struvite can cause scaling of pumps, pipes, in-line sensors and dewatering equipment.

Until 2015 iron chloride was dosed to both the activated sludge system and the digested sludge tank to reduce the phosphate load to head of works (see Figure 2). In this way also struvite scaling in the sludge line was prevented.

**BACKGROUND: BIOLOGICAL PHOSPHATE REMOVAL AND SLUDGE DEWATERING RESULTS**

As mentioned in the introduction, divalent cations in wastewater like magnesium, calcium and potassium can have a positive influence on phosphate uptake from wastewater by PAOs. By enhancing the concentration of magnesium in the influent from 15 to 30 mg/l respectively, an increase in the average P-removal efficiency from 85% to 97% by PAO’s has been reported. It is assumed that municipal wastewater contains an excess of magnesium and that ion limitation of biological phosphate uptake is unlikely to occur. More important factors are volatile fatty acid (VFA) content, pH and food to microorganism ratio and operational parameters which leads to release of phosphate (Mulcerins et al. 2004). However, large wwtp’s like Harnaschpolder may periodically experience short- or long-term shortages of required substances in their influent, due to rain water events and seasonal influences. This can lead to an excessive dosage of metal salts in order to meet the legal effluent requirements, which leads to less luxury uptake by PAO’s, through which a downward spiral is engaged. It can therefore not be ruled out, that additional availability of magnesium can lead to an increased luxurious phosphorus uptake in specific circumstances, such as dosage of magnesium.

The phosphorus effluent quality of Harnaschpolder wwtp is influenced by the phosphorus load in reject water of the sludge thickening and dewatering (Figure 2) and by rain weather events. Activated Sludge Model calculations imply, that if this phosphorus recirculation is minimized, the capacity for biological uptake of phosphorus is probably enough to meet the legal phosphorus effluent requirements. This is without the addition of iron chloride (Meijer 2014).

Several researchers have implied that the introduction of biological phosphate removal processes coincides with less dewaterable sludge. Causes which are suggested are the presence of colloidal proteins, ammonium and potassium and the lack of cations like calcium and magnesium. Through biological phosphate removal in activated sludge, phosphate is released during digestion. This phosphate will often precipitate together with magnesium and ammonium to struvite \((\text{Mg(NH}_4\text{)}\text{PO}_4\cdot6\text{H}_2\text{O})\). In digested sludge a high concentration of potassium and ammonium then remains, along with high concentrations of colloidal proteins (Jardin & Popel 1994; Novak et al. 2003). Cations like magnesium, calcium and iron can play an important role in the matrix of sludge and polymers at dewatering and have a positive influence on the dewaterability. These divalent and trivalent cations can neutralize the negative charge of the sludge and form bridges between the molecules in the sludge. Monovalent cations do not have this ability (Shimp et al. 2013). In the Netherlands, lab and full-scale experiments confirm these results. By dosing magnesium chloride to digested sludge the polymer usage decrease by 40% and the dryness of the dewatered sludge improved from 22.1 to 23.0% dry matter (Berkhof & Korving 2016).

By dosing cations like magnesium to digested sludge, struvite \((\text{Mg(NH}_4\text{)}\text{PO}_4\cdot6\text{H}_2\text{O})\) is formed at pH levels higher than 7. It remains unclear whether this formation of struvite enhances the sludge
dewaterability. Possibly the struvite crystals contribute to the filterability of the sludge. The assumption is that struvite crystals, like other inert materials as coal, calcium and wood can create and maintain canals in the sludge through which water can escape, which would otherwise be trapped in the sludge (Qi et al. 2011).

**FULL-SCALE TEST CONTROLLED STRUVITE PRECIPITATION**

To optimise sludge dewatering and phosphate removal at Harnaschpolder wwp, a full-scale test has been executed since August 2015. In this full-scale test magnesium hydroxide is added to digested sludge. This means that the precipitation of struvite can be restricted to the digested sludge buffer (see Figure 3). This approach differs from most other projects for phosphate removal and recovery from wastewater in Western Europe. First of all struvite is precipitated in digested sludge and not in the reject water of the sludge dewatering process. Secondly, magnesium hydroxide (Mg(OH)₂) is dosed instead of magnesium chloride (MgCl₂), as is more common for struvite recovery processes. Also no auxiliary equipment is necessary to strip carbon dioxide (CO₂) to increase the pH level as magnesium hydroxide is slightly alkaline. This reduces investment costs. Magnesium hydroxide (53% (w/w)) is purchased from Nedmag BV, a Dutch company that produces an unique stabilised suspension. During the test period and in close cooperation with Nedmag a dedicated storage and dosing system was developed.

**Figure 3 | Process scheme controlled struvite precipitation.**

In the second quarter of 2015 the following temporarily equipment was installed:
- Dosing unit and piping for magnesium hydroxide.
- Floating mixer in the digested sludge buffer.

Also a lab method was developed to predict the dry matter content of the sludge (relative accuracy ± 5%). Through this method, different options were tested upfront to find out which dosage options were most effective and efficient. Next these control settings were tested at full scale. The full-scale test has been running since August 2015 up until present day.

**Results full-scale test Harnaschpolder wwp 2016**

By dosing magnesium hydroxide to digested sludge, significant results are achieved. From the start in August 2015 a major improvement in dry matter content of dewatered sludge is observed (Figure 4). Also the following improvements are obtained in 2016 (reference year 2014):

- An excellent quality of the reject water from sludge dewatering is obtained through which the phosphorus load in this reject water returned to head of works is negligible (<100 mg TSS/l and Ptotal < 50 mg P/l). This decrease in combination with other optimisations are beneficial for the biological phosphorus removal process. In 2016 the phosphorus effluent quality remained constant (yearly
moving average Ptotal < 0.9 mg P/l), while 42% less iron chloride was added to meet the legal phosphorus effluent quality requirements (see Figure 5).

- Polymer use decreased by 25% from 18 to 14 g per kg dry solids.
- Dry matter content of the dewatered sludge increased from year average 22% in 2014 to 24% in 2016 (see Figure 4).
- Decrease in sludge production in wet tons by 19% (see Figure 6).

Throughout the test, several technical difficulties occurred such as failure of the magnesium hydroxide storage and dosage system and the mixing equipment in the digested sludge buffer. Due to these technical failures the full scale test was interrupted several times from November 2015 to April 2016 and from October 2016 to December 2016, which influenced the overall year results negatively. For instance, without these technical disturbances the use of iron chloride would have been reduced by 65% instead of 42% as was achieved in 2016. Also excessive struvite scaling was observed in
in-line flow measurements and the internals of the centrifuges in 2015. From the beginning of 2016 struvite scaling is absent.

An important item, which has to be highlighted, is that the decrease of iron chloride usage works positive in three different ways:

- Less iron chloride is purchased.
- Less chemical sludge is produced.
- Less sludge is dewatered, transported and incinerated (see Figure 6).

By dosing magnesium hydroxide overall less sludge is produced. This is mainly due to the increased dryness of the dewatered sludge. However, the full scale test results also indicate that precipitation of phosphate to struvite produces less chemical sludge than precipitation of phosphate with iron chloride in activated sludge. This hypothesis is supported by the decrease of the ratio of tons dewatered sludge to the tons removed COD by wwtp Harnaschpolder by 19% (see Figure 6). This is subject of further investigation in 2017.

**In-line measurement of dewatered sludge dry solids content**

The addition of magnesium hydroxide to digested sludge leads to more stable phosphate concentrations as well as a stable positive cation balance in digested sludge. This changes improved sludge dewaterability. It became obvious that an enhanced process control of sludge dewatering would lead to even better results. Therefore a Valmet® in-line measuring device for dry solids content of dewatered sludge was tested from June 2016 at one of four centrifuges (see Figure 7).

This test was a success. The in-line dry solids measurement was comparable to the laboratory test results. Only minor deviations (up to $\pm 0.2\%$ dry matter) were observed. Following this test, all four dewatering centrifuges were equipped with this in-line dry solids measurement by February 2017. These measuring devices enable the operators to gain insight in the effects of different parameters (polymer dosage, flow and torque) of the sludge dewatering system and adjust them accordingly. Previously the process operators relied on information obtained from a single grab sample per day per dewatering centrifuge.

The next step in optimising the dewatering results, is a test of Total Suspended Solids (TSS) in the reject water on one centrifuge in 2017. If this test is successful a full automated control loop will be installed for the process control of the dewatering centrifuges.
ENVIRONMENTAL IMPACT

Phosphorus in the form of struvite is not recovered at Harnaschpolder wwtp. Instead, from 2018, the phosphorus present in the incinerated sludge ashes will be recovered by the EcoPhos company in Belgium. In this way more than 80% of the influent phosphorus of Harnaschpolder wwtp will be recycled.

The environmental impact of the phosphate removal and sludge treatment including digestion, dewatering, transport and incineration can be calculated based on primary energy use. This calculation method includes not only fossil energy like electricity and natural gas for the wastewater treatment process, but also energy related to the production of chemicals and transport. If a product is produced, which can be used as a raw material, the primary energy for production of this raw material can be deducted. Through this method the use of different chemicals, use of fossil energy and production of raw materials can be compared (Afman et al. 2012; Mulder 2012; Visser et al. 2016).

The environmental impact due to controlled struvite precipitation at the Harnaschpolder wwtp is reduced by 30–40% (see Figure 8). This reduction is predominantly related to using less dewatering polymers and less iron chloride (FeCl₃). The use of FeCl₃ and polymers have a relatively large impact on the environment due to the high energy use for production. The production of Mg(OH)₂ has a relatively low primary energy requirement.

OUTLOOK

After some adjustments made in December 2016 the temporary equipment has functioned without any problems. The results in the first quarter of 2017 are therefore more positive than published in this paper. Exemplary is the use of iron chloride, which decreased in Quarter 1 2017 by 90% (compared to 2014). Only during extensive rain weather conditions additional iron chloride is dosed. Furthermore the process operators are gaining experience in using the information from the in-line dry solids content measuring devices. They are able to operate at highest dewatered sludge dry matter content in combination with an excellent reject water quality (low solids) and a minimal polymer usage. Finally, through this full scale test in combination with other optimisations, a stable phosphate removal in the activated sludge system is achieved. It is expected that the dosage of magnesium hydroxide can be further optimised accordingly. It is expected that the following goals will be achieved in 2017 (in comparison with reference year 2014):
Decrease in use of iron chloride by more than 80%.

Improvement of effluent quality from <1.0 mg PO₄-P/l to <0.8 mg PO₄-P/l based on yearly moving average.

Average dryness of dewatered sludge >24.5% ds.

Decrease in polymer use by 25%.

Decrease in sludge production in wet tons by 19%.

No struvite scaling and blockage in piping and equipment.

Based on the results of the full scale test a permanent installation will be realised. It is expected that the yearly operating costs² of Harnaschpolder wwtp will be reduced by over 4% by 2018. The return on investment is estimated at 1.5 years. Compared to other P-recovery techniques from sludge, which have a return on investment of 5–10 years, this is a cost effective alternative approach with a major positive environmental impact.

REFERENCES


² Operating costs are all expenses related to the operation of the wtp but do not include capital costs (depreciation).
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