Experience with phosphorus removal and sludge handling and disposal in Flanders

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Abstract The way excess sludge must be disposed of is a key factor in the choice of the appropriate phosphorus removal technique at municipal wastewater treatment plants. In Europe the ongoing trend of tightening the sludge spreading rules called for a serious reduction of its agricultural utilisation and the expansion of the (co-)incineration disposal route, which led to a shift towards more sophisticated sludge handling techniques. This paper illustrates the impact of different sludge handling techniques on the performance of chemical and enhanced biological phosphorus removal at municipal WWTPs. The main conclusion is that although enhanced biological phosphorus removal is particularly sensitive to the problem of return liquors from sludge treatment processes indirect dewatering and anaerobic stabilisation cannot be discarded altogether when considering its implementation.

Keywords Chemical precipitation; full-scale; phosphorus removal; sludge handling techniques; sludge production

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Introduction

Aquafin NV is a private company responsible for pre-financing, design, construction and long-term operation of the collectors, pumping stations and municipal wastewater treatment plants (WWTPs) of the Flemish region (5,927,000 inhabitants). In the transposition of the EU Directive 271/91 on Urban Wastewater Treatment, the whole region was designated a sensitive area. This meant the implementation of nutrient removal, nitrogen and phosphorus, at all WWTPs serving agglomerations with more than 10,000 population equivalents (PE), 118 in total.

Based on several comparative technical-economic studies, for new WWTPs simultaneous chemical precipitation with iron salts was implemented in agglomerations between 10,000 and 20,000 PE and enhanced biological phosphorus removal (EBPR) in agglomerations larger than 30,000 PE. For agglomerations between 20,000 and 30,000 PE and for the retrofitting of existing installations the decision-making was based on tailored studies (Ockier *et al*, 2001).

Now that almost all installations have been built or renovated and all comply with the standards, the attention is directed almost exclusively toward the economic performance of the installations. In the context of a comprehensive regional programme to minimise the sludge production — which is the major single operating cost — Aquafin conducted a study to quantify the possible reduction of the sludge production that can be achieved by switching further from chemical phosphorus precipitation to EBPR and the technical and economic implications involved.

In the mid-nineties a Regional Executive Order called for very stringent standards for the sludge spreading to land, which led to a serious reduction of this practice and the expansion of the (co-)incineration disposal route, which led to a shift towards more sophisticated sludge handling techniques, including anaerobic sludge stabilisation and thermal drying. This situation is familiar to other European regions and soon many others will likely follow (European Commission, 2000).

A key factor in the evaluation was the impact of the phosphorus removal technique on the performance of the sludge treatment and the impact of the sludge treatment on the performance of phosphorus removal. Sludge liquors may recycle a relevant portion of P to the liquid stream and EBPR is particularly sensitive to this problem.

This paper summarises hands-on experience gained on phosphorus removal and, in particular, will evaluate the impact the various sludge handling techniques may have on its performance.

Materials and methods

Full-scale data from 81 facilities using simultaneous chemical phosphorus precipitation and 23 with enhanced biological phosphorus removal (EBPR), of which four were combined with partial chemical phosphorus precipitation, were reviewed.

Data included size, influent characteristics, effluent results, cost and consumption of precipitant agents, and key operating parameters such as temperature, MLSS concentrations, sludge settleability, excess sludge production and DS content of the dewatered sludge. Specific tests carried out for this or other studies were also considered.

The impact of sludge handling techniques on EBPR was assessed for one or several of the following on-site options:

- Sludge thickening: gravity (7) or mechanical (9) thickening
- Sludge dewatering: belt presses (6), filter presses (1) or centrifuges (3)
- Drying: thermal drying (1)
- Sludge stabilisation: anaerobic digestion (1)

Process stability and perfomance

EBPR

The early nineties' decision to invest in EBPR was quite controversial. At the time the technological risk associated with EBPR was still regarded as an important factor in the comparative analysis. In Europe, full-scale experience with EBPR was quite limited and several difficulties related to the process stability were reported. Moreover, literature indicated that the Flemish sewage was too weak to sustain the required P-removal efficiency and the possible inhibitory effects of partial phosphate removal through addition of precipitant salts (hybrid system) were not fully known.

Practical know-how and insight in the predictability of process stability has now been gained, the effluent norms are respected and only 4 out of the 23 EBPR systems need to be backed up by partial chemical precipitation.

The average P removal results in 2003 of the EBPR facilities are illustrated in Figure 1 and the effluent requirements in Table 1. In Figure 1, the horizontal axis depicts the number of the facility and the vertical axis shows the yearly-average phosphorus concentration in the influent and in the effluent (primary Y-axis) as well as the BOD/P ratio of the sewage (secondary Y-axis).

Figure 1 shows that all WWTPs complied with the effluent limit concentration requirements (indicated with the continuous line), despite the fact that the yearly-average BOD/P ratio of the sewage was in 70% of the cases lower than the process stability threshold indicated in literature (in Figure 1 indicated with a discontinuous line).

On the other hand, nine installations would not have complied with the 80% P-removal standard that will have to be met from 2006. Stormwater is the main factor contributing to the lower removal. While during dry weather flow EBPR is consistently achieved (removal efficiencies between 75% and 95%), during prolonged periods of stormwater flow the extent of phosphorus removal generally decreases to less than 60% (Bixio *et al.*, 2004). This can be regarded to a certain extent as a local problem, because

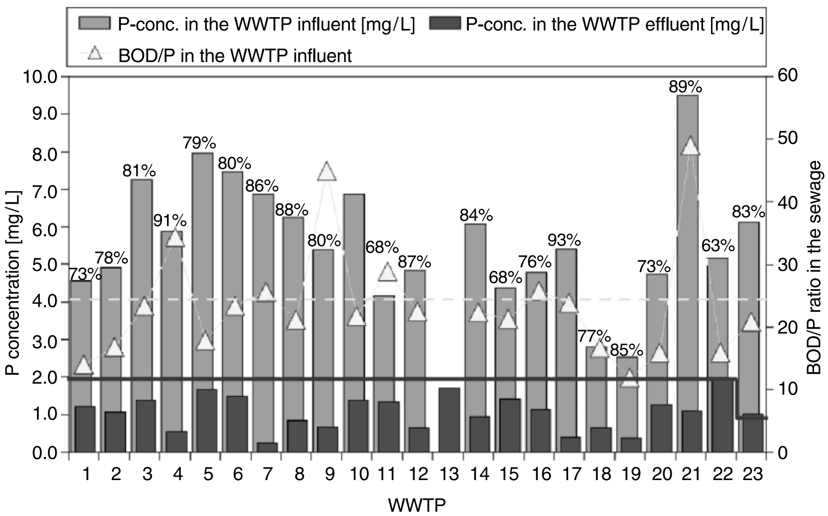

Figure 1 Yearly-average phosphorus concentration in the influent and in the effluent and BOD_5/P in the influent (secondary Y-axis) of the Flemish WWTPs using EBPR in 2003

of the wet climate, the combined sewer network and the fact that stormwater flow to the secondary treatment may account for up to 10 times the dry weather flow (that is, 4 times more than in many other European regions).

Simultaneous chemical precipitation

In Flanders P-precipitation is achieved by means of ferric salts ($FeCl_3$ or $FeClSO_4$). Estimates of the "unity" chemical doses applied, expressed in mol Fe^{3+}/mol $P_{removed}$, in the period between September 2001 and October 2002 are reported in Table 2. The unity doses were derived assuming that the natural phosphorus assimilation in the sludge is 0.017 g P/g DS.

Table 2 shows that the estimated yearly average $Fe/P_{removed}$ of 80% (i.e. from 10%ile to 90%ile) of the treatment works using chemical precipitation is between 0.43 (10 percentile) and 2.54 mol Fe/mol P (90 percentile), with a median of 1.05 mol Fe / mol P.

The reduction in sludge production in switching from chemical to biological P-removal was estimated to be as little as 1.5% of the total sludge production when median chemical dosages are applied, but as high as 13% (or higher) for those facilities

Table 1 Effluent requirements in agglomerations larger than 10,000 PE in the Flemish region

Population equivalents		Annual average mg/l	Daily maximum mg/l	Annual average (Until 31/12/2005) %	Annual average (From 1/1/2006) %
10,000–100,000	BOD	–	25		90
	COD	–	125		75
	SS	–	35		90
	TN	15	20	75%*	80
	TP	2	–	75%*	80
> 100,000	BOD	–	25		90
	COD	–	125		75
	SS	–	35		90
	TN	10	20	75%*	80
	TP	1	–	75%*	80

*Minimum percentage reduction of the overall load of N and P for *all* WWTPs

Table 2 10, 50 and 90 percentiles of the estimated yearly-average chemical requirement, expressed in molar $Fe/P_{removed}$ ratio, for each P-removal alternative

	10%ile	50%ile	90%ile
Simult. precip. (87 WWTPs)	0.43	1.05	2.54
Hybrid (4 WWTPs)	0.09 (best)	0.10–0.32 (other two)	0.63 (worst)

that apply a dosing rate of 2.54 mol Fe/mol P (or higher). The incremental sludge production was estimated considering that EBPR generates 3.4 g DS/g P and that ferric salts generate 4.87 g DS/ g P when bound with phosphates or 3.45 g DS/g Fe when not (Henze *et al.*, 1995). It is also worth mentioning that ongoing results indicate that under normal operating conditions (i.e. low P concentrations) the dosage rate is only slightly dependent on the initial P concentration.

The use of on-line phosphate analysers for process control did succeed in reducing the dosage rate of the precipitant agents (Devisscher *et al.*, 2002). In our experience several reliable and effective on-line analysers are available on the market and their use can be profitable. Devisscher and Parmentier (2003) calculated that the payback periods of the on-line analysers can be lower than 3 years for chemical phosphorus precipitation facilities above 75,000 population equivalents when the sludge is to be disposed of through the incineration route (the median unity cost of the precipitant agent being 0.50 EUR/kg Fe^{3+}). Now 10 on-line analysers are operational and several others are to be started up.

Sludge handling and disposal

Sludge thickening and dewatering may recycle a relevant portion of P to the liquid stream through the sludge liquors. EBPR is particularly sensitive to this problem.

Does EBPR necessitate direct dewatering?

In the early nineties in Flanders direct dewatering was generally regarded as a prerequisite when using EBPR to sustain the required P-removal efficiency, as with this type of process no phosphates are returned to the intake of the treatment plant. This requisite is in some cases an additional economic burden that plays against a more widespread adoption of EBPR.

Yet, despite the fact that the proportion of P in the sludge back to the liquid stream may indeed be substantial, now the possibility of combining indirect dewatering with EBPR is no longer discarded altogether.

Indirect dewatering in EBPR plants may recycle up to 40% of the influent P. The WWTP Ieper represents a worst-case scenario. The sludge treatment is composed of gravity thickeners, a buffer and centrifuges; the system is fully loaded. The average effluent P concentration in 2003 was 1.5 mg P/L with a percentage reduction of 80% (WWTP 6 of Figure 1). Co-precipitation occurs only during intense rain events, when high nitrate concentrations leaching from agriculture enter the system.

The portion of P in the influent originating from the sludge liquors and the P-removal efficiency of WWTP Ieper in the period 9–20 July 2001 is illustrated in Figure 2. During (and preceding) the measuring campaign no precipitant agents were added into the system.

Figure 2 shows that the facility could attain effluent concentrations well below the 2 mg P/L effluent standard. Note that a P-removal performance of 90% was obtained while the phosphorus concentration in the sewage was of around 10 mg P/L and, on average, 26% of the influent P load was recycled to the inlet of the facility through the sludge liquor.

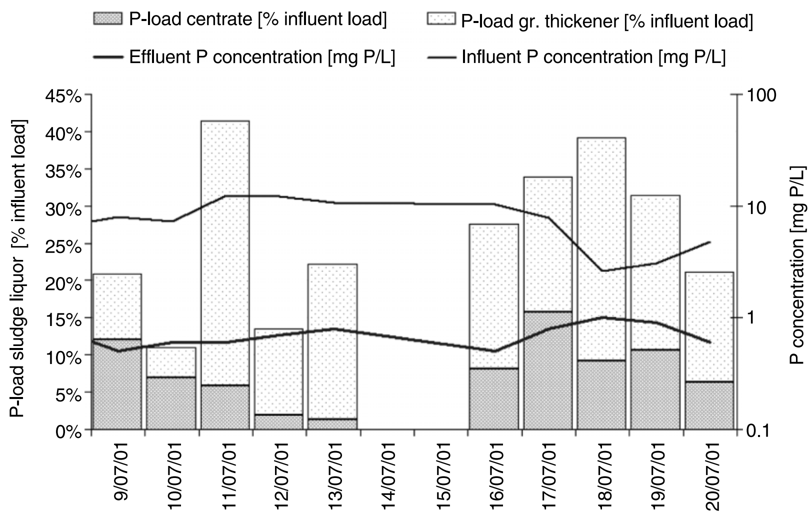

Figure 2 Influent and effluent P concentrations and portion of the influent P load originated from the sludge liquors at the Ieper EBPR scheme in the period 9–20 July 2001.

In Flanders gravity thickening (and centrifugation) may in some cases be an economic alternative to direct dewatering, even in those situations where partial phosphate removal from the supernatant to sustain the required P-removal efficiency is required.

Concerning the effects of dewatering using filter presses, our experience at WWTP Menen indicates that the P content in the sludge liquor is negligible as a result of the conventional dosing rates of iron salts applied in the normal operation of the filter presses.

Is EBPR incompatible with anaerobic digestion of the waste sludge?

In the early nineties in Flanders stabilisation of the waste sludge with anaerobic digestion was generally regarded as incompatible with the use of EBPR, as the excess phosphorus accumulated by EBPR would almost entirely be released in the bulk liquid when the sludge is digested.

On the other hand we now know that part of the released phosphorus is refixed. WWTP Leuven represents a worst-case scenario. The sludge treatment is composed of thickening tables, a buffer, anaerobic digesters, a buffer, centrifuges and a thermal drier. The system is fully loaded. The effluent consent is 1 mg/l and in 2003 the average effluent P concentration was 1.0 mg P/L with a percentage reduction of 83% (WWTP 23 of Figure 1). Co-precipitation is needed, but it is limited (0.5–2.0 mg Fe^{3+}/L). At WWTP Leuven, the TP concentration in the centrate doubled (from 55–70 mg P/L to 120–170 mg P/L) when the system was upgraded to EBPR.

The portion of P in the influent originating from the sludge liquors at WWTP Leuven in the period 12–30 May 2004 is illustrated in Figure 3. During the measuring campaign an average of 0.5 mg Fe^{3+}/L was added into the system. The salts were dosed just after the digester.

Long-term results from WWTP Leuven now indicate that only a limited partial phosphate removal from the supernatant is needed, despite the fact that anaerobic sludge digesters in EBPR plants may lead to a P recycle up to 25% of the influent P.

The economic viability of anaerobic digestion with EBPR should be reviewed. Literature indicates that with EBPR, anaerobic digestion could indeed be an economic alternative (Eekhof et de Jong, 1997; Jardin, 1996).

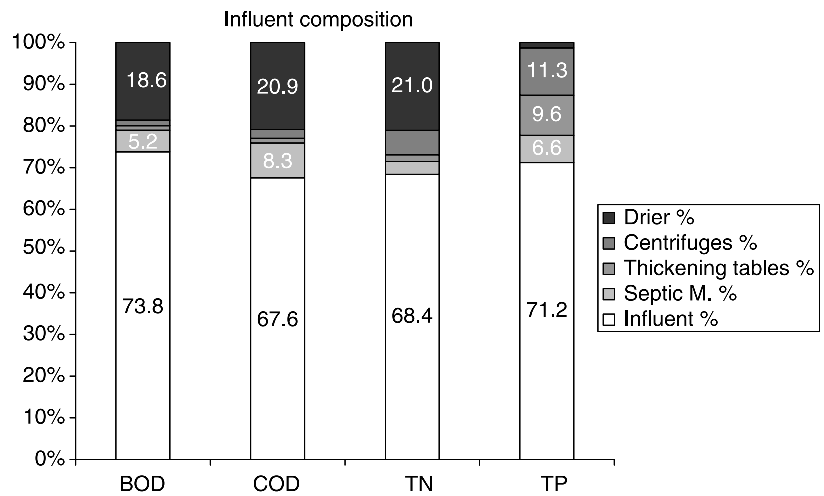

Figure 3 Influent and effluent P concentrations and portion of the influent P load originated from the sludge liquors at the Ieper EBPR scheme in the period 12–30 May 2004.

Figure 3 also shows that thermal drying discharges a very limited amount of phosphorus back to the liquid stream. It does only slightly affect biological P removal, in an indirect manner, because of the slightly higher recycle of TN than of BOD.

Did P removal affect the ultimate disposal route of the (dried) sludge?

The ultimate disposal route of dried sludge with P removal was not influenced by the different properties of the sludge produced, whether this is for (co-)incineration, N-VIRO or for applications as aggregates (e.g. cement industry). For the cement industry, the limit on the P content, expressed as P_2O_5, is 6% DS. This was attained in none of the cases.

The co-incineration of dried sludge can be affected by the increase in the chlorine and the sulphur content of the dried sludge due to chemical P-precipitation. The limit of respectively 4,000 mg Cl/kg DS and 15,000 mg S/kg DS were however not a problem at the dosing rates applied.

Chemical precipitation has also the potential, depending on the source of the material, to add significantly to the PTE burden. Cadmium and nickel contamination are of particular concern.

It is also worth mentioning that P-removal may affect the agricultural utilisation of the sludge, as phosphorus removal can affect the fertilising value of the sludge. Smith *et al.* (2002) showed that sludge from EBPR has the highest phosphorus extractability in soil whereas iron dosing slightly reduces or has no effect on phosphorus release, depending upon the type of soil. In other words, chemical P precipitation will increase sludge production while not improving the availability of P for use in agriculture. Smith *et al.* (2002) showed that high-temperature drying significantly reduced the extractable-P content in sludge by 20–60%, compared to dewatered digested cake, and release from thermally-dried sludge declines further with iron enrichment.

Conclusions

The Flemish experience shows the following.

- EBPR can attain the P-removal efficiencies required to fulfil the Urban Wastewater Treatment Directive standards even with weak and rather unfavourable sewage characteristics.

- For facilities using chemical precipitation the estimated yearly average ferric dosages are in a molar Fe/P ratio between 0.43 (10 percentile) and 2.54 (90 percentile) for 80% of the projects, with a median of 1.05. The difference in sludge production between the two P-removal processes was estimated to be as little as 1.5% of the total sludge production when median chemical dosages are applied, but as high as 13% (or higher) of the total sludge production for those facilities that apply a dosing rate of 2.54 mol Fe/mol P (or higher).
- The use of on-line analysers for process control has proven to be reliable and capable of substantially reducing the dosage rate of the precipitant agents.
- From a process point of view direct dewatering is the best dewatering option when using EBPR. However, indirect dewatering is not necessarily incompatible and can in some cases be more economical than direct dewatering.
- Anaerobic digestion can also be combined with EBPR. The addition of chemical precipitation to limit the P in the return liquors is limited.
- The changes in the properties of the sludge brought about by P-removal did not influence the type of ultimate disposal route of the sludge.

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