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PHOSPHORUS BALANCE AT TARTU WWTP, ESTONIA

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ABSTRACT

Sewage sludge is usually considered as treatment residue that needs expensive treatment for removal. The treatment and handling of sludge can form 20 to 50 % from a wastewater treatment facility's costs. Sludge volumes will continue to grow worldwide with increasing population and country wealth. In a sustainable society, sludge should rather be seen as a source of energy, phosphorus and other products. Water treatment facilities are exploring technologies to utilise these values worldwide. Technologies on extracting minerals from sludge would either help offset treatment facility's costs or even turn a profit. First step in turning sludge from a costly waste material into a profitable revenue stream should be a material balance.

In Tartu wastewater treatment plant (120 000 pe, 28 000 m^3 d^{-1}) waste water is treated by activated sludge process with an integrated biological nitrogen and phosphorous removal. Sludge is dewatered and stabilized by windrow composting. In the treatment plant, phosphorus balance in various treatment steps was studied and potential technologies for extracting phosphorus were reviewed.

KEYWORDS

Phosphorus removal, recovery and reuse; extraction, balance, sludge, struvite; wastewater

1 INTRODUCTION

1.1 Phosphorus – a limited or abundant resource

Phosphorus (P) is an essential macronutrient for crop production. Agriculture accounts for about 80% of the phosphate ore utilisation worldwide, which is finite and non-renewable resource. Current phosphate deposits may last for only a hundred years at the present depletion rate [1]. Phosphorus may become a limiting substance in the future and phosphorus leakage from existing sludge deposits may become a diffusive phosphorus source. The excess content of phosphorus in receiving waters leads to intensive algae and hydrophyte growth, known as eutrophication.

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Biological phosphate removal in activated sludge processes was reported in seventies [2–4], and currently it is a common phosphorus removal step in most modern treatment plants. However, as phosphorus concentrations in effluent water decrease, phosphorus concentrations in waste activated sludge (WAS) increase. Increased phosphorus concentrations in WAS lead to two significant problems commonly faced by plant operators: undesirably high levels of phosphorus in sludge intended for land application, and struvite clogging during anaerobic treatment [5, 6].

Sewage sludge is usually considered as treatment residues, which is expensive to get rid of. The treatment and handling of sludge can represent between 20 and 50 % of a wastewater treatment facility's costs. Sludge production volumes will continue to grow worldwide with increasing population and country wealth. In a sustainable society, sludge should rather be seen as a source of energy, phosphorus and other products. Water treatment facilities are exploring technologies to extract these values worldwide. Technologies on extracting minerals from sludge would either help offset treatment facilities costs or even turn a profit.

1.2 Extraction of P, review

There are currently several alternative ways to remove phosphorus from wastewater enabling its recovery and reuse as fertilizer [7]:

- improved sludge quality at treatment plants and use of the sludge for agricultural purposes,
- improved wastewater treatment systems using reactive filter media,
- processing of the sludge into separate fractions to obtain phosphorus containing products with a high purity,
- processing of sludge incineration ashes to obtain phosphorus containing products,
- phosphorous crystallisation in the effluent process flow,
- combined precipitation of phosphorous and nitrogen in the wastewater,
- phosphorous adsorption on activated clay,
- ion exchange in the effluent process flow,
- acid P-extraction and precipitation.

Direct application of sludge compost

Biological removal of phosphorus generates large amounts of sludge, which is costly to manage and does not always allow efficient phosphorus recovery. Sludge compost has been preferred instead of liquid application. Sludge drying, pelletizing or briquetting has been practiced to achieve more hygienic application, and slower release of nutrients.

Filter substrates

There is a large variety of reactive porous filter substrates, rich in Ca, Fe or Al with a high affinity for P [8–10]. The mechanisms of P retention involve sorption processes at the surface of the material. Once saturated with P the material could be recycled back to agriculture. P in the material should be in a form capable of desorbing and being released to the soil P solution, thus becoming available to plants [8].

Formation of Struvite

Phosphorus recovery through struvite ($MgNH_4PO_4 \times 6H_2O$) crystallization and the possible reuse of struvite as a fertilizer is widely reported [5, 11–14]. Safe and quick extraction of high purity calcium phosphate, magnesium phosphate or Struvite pellets has been studied by many authors. The formation of magnesium phosphates such as $MgHPO_4 \times 3H_2O$ (newberyite),

$Mg_3(PO_4)_2 \times 8H_2O$ (bobierrite) and $Mg_3(PO_4)_2 \times 22H_2O$ (cattiite), during struvite crystallization or dissolution process, is reported already in early works [15] as well as late ones [16]. A complete phosphorus removal and recovery from anaerobically digested sludge liquors as struvite has been implemented in Japan, and the resulting product sold to fertiliser companies [17, 18]. Struvite can be used as slow release fertilizer at high application rates, without the danger of damaging plant roots. Granular forms of struvite are one of the best, slow release phosphorus fertilizers [17, 19].

Microwave extraction
Phosphorus in sludge can be released into solution by heating it to 50 to 70°C prior to anaerobic digestion with microwave irradiation [6]. Domestic and industrial microwave ovens generally operate at a frequency of 2.45 GHz corresponding to a wavelength of 12.2 cm and energy of 1.02×10^{-5} eV [20]. Unlike anaerobic processes, the phosphorus released consists of a significant fraction of phosphorus that is not orthophosphate. Likely mechanisms for release include cell membrane disruption, causing the release of stored polyphosphate into solution, and the release of phosphorus trapped in extracellular polymeric material. Microwave irradiation also causes the release of arsenic, molybdenum, nickel, and selenium into solution [6], which is a problem in case they are present in wastewater.

Solvent extraction
Inorganic phosphorus can be extracted and separated from municipal wastewater with primary amine as a solvent in the presence of sodium molybdate [23].

Phosphorus recovery from sludge ash
Phosphorus recovery from sludge ash has been studied [21]. After the thermo-chemical treatment at 1000ºC, a mechanical finish transforms the clean phosphate semi-product to marketable phosphate and complex fertilizers. Direct phosphorus recovery from sludge incineration ash by leaching with acid or base has been shows, that acid leaching allows to recover phosphorus as iron phosphate, which, however, has low commercial value [22].

1.3 Phosphorus balance in treatment plant

First step in turning phosphorus-rich liquids or sludge from a costly material to treat into a profitable revenue stream should be a material balance. In Tartu Wastewater Treatment Plant (WWTP), phosphorus balance in various treatment steps was studied, aiming to find potential technologies for extracting phosphorus.

2 MATERIAL AND METHODS

2.1 Tartu treatment plant

Tartu WWTP is serving Tartu town and adjacent regions nearby Tartu with the capability of 120 000 pe and 28 000 $m^3\ d^{-1}$ [24]. According to the current process, the technological concept of the WWTP is activated sludge treatment with nitrogen removal according to the modified Ludzack Ettinger (MLE) concept, and integrated biological phosphorous and nitrogen removal according to A2/O process. In addition to the biological phosphorous removal, chemical phosphorous removal with iron(III)sulphate is integrated. The chemical precipitate is mixed into the organic excess sludge. Sludge is dewatered, and stabilized by windrow composting. The working parameters are in *Table 1*.

Table 1. The efficiency of the Tartu WWTP

	Influent mg L^{-1}		Effluent mg L^{-1}	
	Planned	Actual	Limit value [25]	Actual
Biochemical Oxygen Demand, BOD_7	257	120–300	15	4–10
Chemical Oxygen Demand, COD	510	180–1 200	125	25–55
Suspended Ssolids, SS	357	150–650	15	7–12
Total Phosphorus, P_{tot}	10.7	7–15	1,0	0.6–2.0
Total Nitrogen, N_{tot}	51	30–60	10	6–17

2.2 Sampling

Eight sampling points were taken from the most characteristic locations of the WWTP, where high values of dissolved phosphorus were expected. The sampling points are numbered on a layout of the treatment plant, *see Figure 1*.

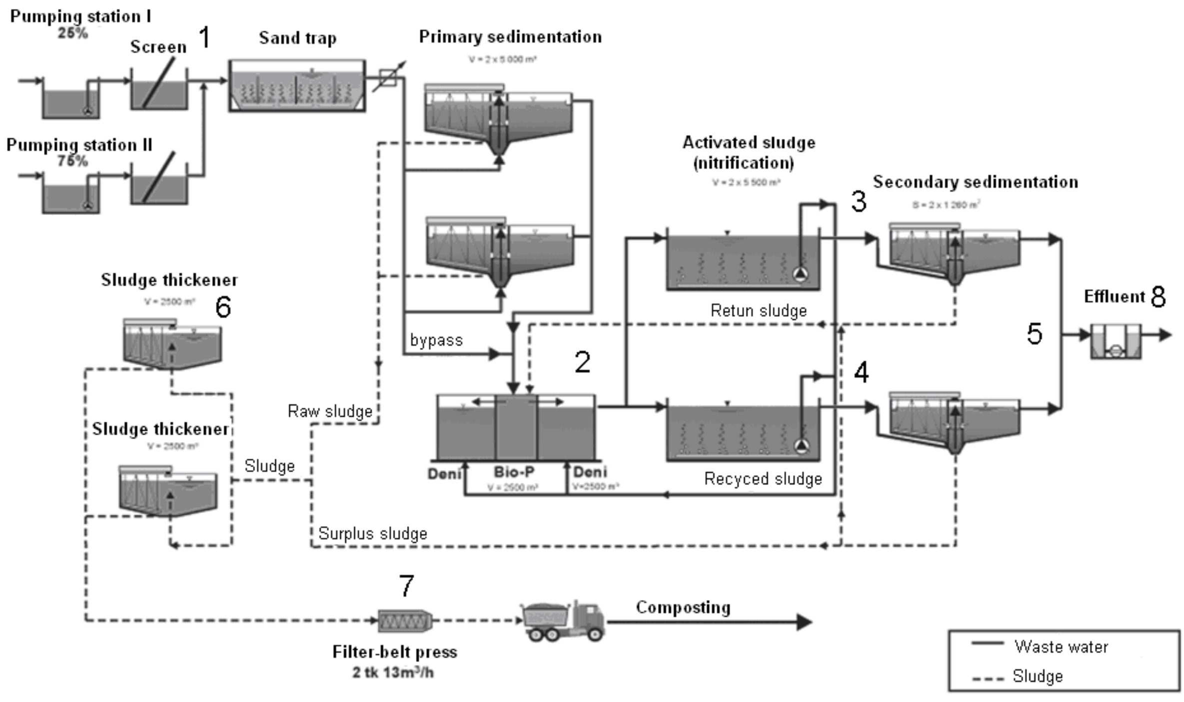

Figure 1. Location of sampling points at Tartu WWTP

2.2 Laboratory procedures

Total phosphorus and phosphates, as well as pH, conductivity, and COD were analyzed at the accredited laboratory of Tartu Waterworks Ltd. All the analytical methods were recommended by EU and ISO standards, all the samples were filtered.

3. RESULTS AND DISCUSSION

The results show that sludge liquor contains about 100 mg/l total phosphorus, most of this (87 – 95 %) as a dissolved phosphates. Second largest concentration of phosphorus was measured in surplus activated sludge – 41 mg L^{-1}. Concentrations in influent to the WWTP were as large as concentrations from anoxic zone, designed as for P-removal – 5.68 and 5.35, respectively (*Table 2*).

The average hydraulic flow was 31 332 m^3 d^{-1} on the particular sampling days. The total phosphorous load on these days was 210 kg d^{-1} and the yearly average load is 300 kg d^{-1}. The total hydraulic load is 12 156 669 m^3 y^{-1} on the year 2009 what makes phosphorous load between 82–110 t y^{-1}. Effluent from WWTP is still consisting phosphorous 0.7–0.9 mg L^{-1} what makes 8.5–11 t y^{-1}. It means that 72–100 t/y is possible range for phosphorous recovery from Tartu WWTP.

Table 2. Characteristics of the samples

Sampling point	P_{tot} mg L^{-1}	PO_4^{3-} mg L^{-1}	COD mgO L^{-1}	Conductivity mS cm^{-1}	pH pH unit
1. Influent to WWTP	5.58	4.24	214	1.26	7.77
2. Effluent from anoxic area	5.68	5.35	76	1.20	7.22
3. Effluent from aeration tank no 1	0.28	0.17	53	1.13	7.42
4. Effluent from aeration tank no 2	0.19	0.09	62	1.10	7.43
5. Effluent from secondary sedimentation tank	0.73	0.55	34	1.14	7.31
6. Surplus activated sludge	40.9	38.5	213	1.15	6.89
7. Sludge liquor	98.5	89.2	190	2.22	6.99
8. Effluent from WWTP	0.72	0.44	37	1.14	7.88

4. CONCLUSIONS

Recovery of phosphorus for recycling, rather than its transfer into dewatered sewage sludge, may offer economic and environmental rewards for the water industry. In Tartu, Estonia, 82–110 tons of phosphorus enters into the WWTP, and 71–100 tons is removed as part of dewatered sludge. Large proportion of it could be removed from liquid phase in most phosphorous abundant sources, e.g. sludge liquor.
For the phosphate industry, extraction of nutrients holds out the promise of a significant source of sustainable raw material – phosphorus, which is comparatively free from heavy metals. These benefits must be compared with the investment and running costs of phosphorus recovery installations.

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