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# Tertiary Treatment of Wastewater by Phosphorus Precipitation – Pilot Scale Test of Flotation Utilization for Suspension Separation

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A research published in this paper is focused on a phosphorus removal from municipal wastewater. A technology consisting of chemical precipitation and flotation was tested to simulate a tertiary stage of wastewater treatment plant. Biologically treated wastewater with a very low concentration of total phosphorus (approx. 1.2 mg/L) was used. The ferric sulphate solution was used as a precipitant. The precipitate was removed by dissolved air flotation which took place in a pilot scale flotation unit Kunst-i-flot. This is an experimental device that was designed for thickening of sewage sludge (inlet pump flow ranges from 0.7 to 5.0 $m^3$/h).
The target of the experiments was to determine whether this technology is applicable in case of low inlet concentration of total phosphorus in the wastewater. The influence of the ratio $Fe^{3+}$/P, the amount of air used for flotation and the hydraulic retention time in the tank for slow mixing were studied. The significant influence of ratio $Fe^{3+}$/P was proved, while increasing of air fed in flotation unit had no positive effect. It was found an optimum dose of ferric sulphate solution approx. 2 g $Fe^{3+}$/g P. The phosphorus removal efficiency was 50 %. Increasing of ferric sulphate dose did not decrease the phosphorus concentration in wastewater effluent, which was usually approx. 0.4 mg/L and higher.

## 1. Introduction

Phosphorus is one of the serious pollutants contaminating wastewater. Phosphorus contained in an effluent from a wastewater treatment plant (WWTP) causes eutrophication of surface water. It is a reason of discharge standards on this element, e.g. the 91-271 EEC directive requires in sensitive areas less than 2 mg/L of total P for WWTP of 10,000 to 100,000 population equivalent (PE) or less than 1 mg/L of total P for WWTP larger than 100,000 PE. The concentration of total P in raw wastewater is from 4 to 16 mg/L (Tchobanoglous and Burton, 1991). On the other hand, wastewater is certain to be a source of phosphorus in the future, as Weiwei and Qiong (2013) have reported. Many researchers address this topic (Muster et al., 2013).
Phosphorus can be removed by biological or chemical processes. In the biological processes of phosphorus removal the microorganisms consume phosphorus containing substances and incorporate it into their cells. The chemical processes precipitate the inorganic forms of dissolved phosphates by their conversion into suspended solids. Phosphorus incorporated into the cells of microorganisms or forming chemical sludge is then usually treated in the frame of sludge management.
Chemical processes commonly use the salts of multivalent metal ions such as calcium hydroxide, aluminium chloride or sulphate or ferrous or ferric sulphate (e.g. Lin, 2001). There are several locations where the chemicals can be dosed; generally there are three strategies, as described by Tchobanoglous and Burton (1991):

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- Pre-precipitation – chemicals are added to raw wastewater and the precipitation occurs in a primary settling tank.
- Co-precipitation – chemicals can be added to several streams based on used technology of wastewater treatment and the precipitation occurs in a biological stage and the solids are removed in a final settling tank.
- Post-precipitation – chemicals are added to the effluent from the final settling tank and removing of the suspension is realized by tertiary treatment (e.g. filter).

This paper presents results of experimental pilot tests of phosphorus precipitation from the purified wastewater. These tests simulated tertiary treatment (post-precipitation), but the phosphorus is removed also in the frame of biological stage by co-precipitation at the WWTP where the experiments occurred. So the concentrations of total phosphorus in treated wastewater were very low. The suspension was separated using dissolved air flotation.

## 2. Materials and methods

The pilot tests took place at WWTP with a capacity of 30,000 PE. This mechanical-biological WWTP contains a simultaneous precipitation of phosphorus. Sludge management is based on the principle of anaerobic stabilization. The average concentration of total phosphorus (as P-tot) in purified water was 0.8 mg/L in 2012. The concentration of P-tot ranged from 0.5 to 1.8 mg/L during the experiments.

### 2.1 Pilot scale unit

A pilot scale unit consists of two parts – a stage of chemical precipitation and a stage of dissolved air flotation (as presented in Figure 1; Figure 2 shows 3D models of the most important apparatuses).

Purified wastewater (at maximum flow rate 1.5 L/s) is pumped from a final settling tank effluent and it flows to a tank for rapid mixing. The 40 % solution of ferric sulphate is added from a storage tank. A hydraulic retention time (HRT) in the tank for rapid mixing is approx. 100 s. The mixture of water and ferric sulphate flows by gravity into a tank for slow mixing where precipitation occurs. The HRT in a tank for slow mixing ranges from 10 to 20 min based on purified wastewater flow rate.

The suspension is pumped from the tank for slow mixing into the second stage, where dissolved air flotation proceeds. The suspension is mixed with pressurised water – recycle stream from the flotation tank. Recycle stream is saturated with air under pressure of 3 to 5 bars. Aeration of recycle occurs in a saturation vessel 2,100 mm high and 200 mm in diameter. The mixture of suspension and water saturated by air flows into a flotation tank (volume of 4.5 $m^3$), where the pressure is reduced and fine bubbles nucleate from the saturated solution. Microbubbles attach the particles of precipitate and rise them to the surface. The floating layer is removed by a skimmer which can be operated continuously or discontinuously.

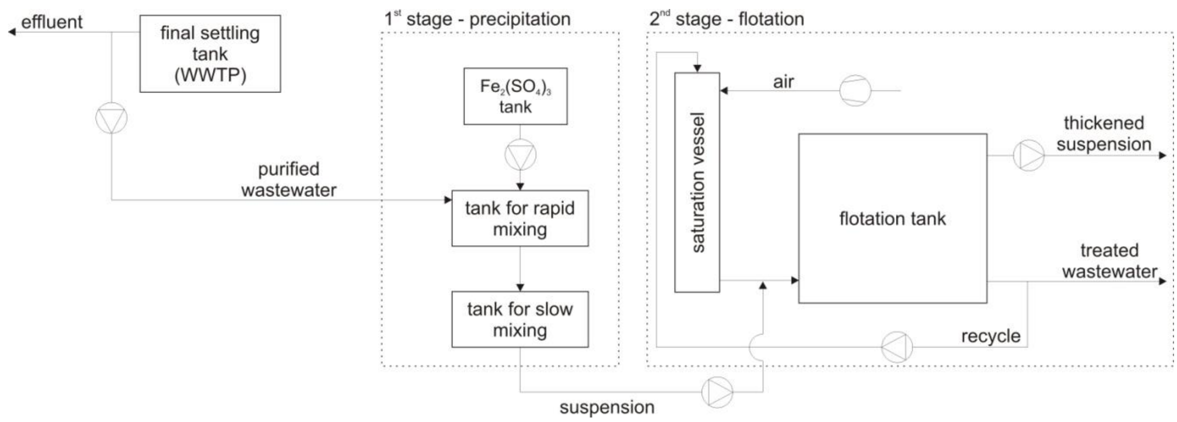


*Figure 1: Flow sheet of the pilot scale unit*

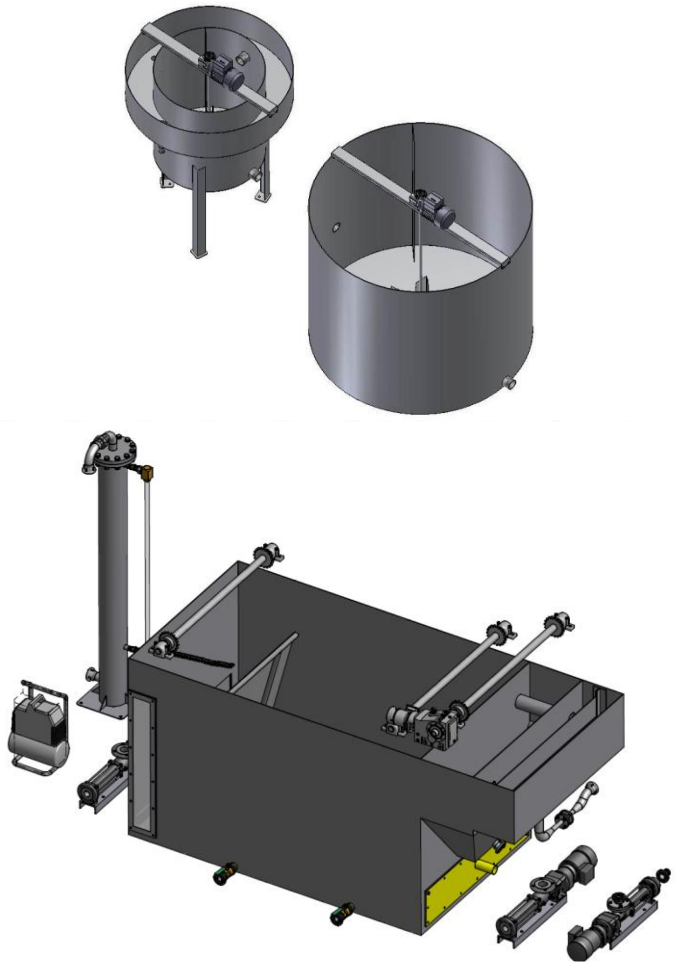

*Figure 2: 3D model of tank for rapid mixing, tank for slow mixing, flotation tank with peripheries (left to right)*

**2.2 Experiment description**

The flow rate of purified wastewater (ww) was usually kept at 1.4 L/s. The amount of precipitant was fed based on required $Fe^{3+}$/P ratio (the range from 1.7 to 5 g/g was studied); the amount of phosphorus was determined approximately. The flow rate of recycle was regulated based on an auxiliary variable called “specific air input”. This variable was derived from the commonly used formula for calculating air-solids ration A/S, reported e.g. by Tchobanoglous and Burton (1991). Eq(1) shows the calculation:

$$m_{air,in} = 1.3 \cdot S_a \cdot (F \cdot p - 1) \cdot \frac{Q_R}{Q_{ww}} \quad (1)$$

where $m_{air,in}$ (mg/L ww) is specific air input, 1.3 (kg/m$^3$) is air density, $S_a$ (mL/L) is air solubility in water, $F$ (-) is fraction of air dissolved at pressure $p$, $p$ (atm) is absolute pressure in saturation vessel, $Q_R$ (L/s) is recycle flow, $Q_{ww}$ (L/s) is wastewater flow. The data for calculations were adopted from Perry (1997) and Wang et al (2010).

The experiments were focused on evaluation of following:

- influence of $Fe^{3+}$/P ratio,
- influence of air input,
- influence of HRT in the tank for slow mixing.

The decrease of concentration of total phosphorus (P-tot) and inorganic phosphorus (P-$PO_4$) was the main evaluative criterion. The samples of purified wastewater were collected from an outside ring placed on the top of tank for rapid mixing. The samples of treated wastewater were collected from an overflow space of flotation tank. The samples were analysed in external laboratory. When the results of analysis had come

from an external laboratory, the values were adjusted. The samples both of input and outlet wastewater were collected at the same time (approx. 2 h after the unit setting).
Only thin layer of thickened suspension was formed at the surface, so the skimmer removed it every 2 h (run of the skimmer was only 5 min).

## 3. Results and discussion

### 3.1 Influence of $Fe^{3+}$/P ratio on phosphorus removal efficiency

The amount of $Fe^{3+}$ dosed to the phosphorus influent is the most important parameter that affects the efficiency of phosphorus removal. It is presented in Table 1. The results presented here were measured at the same operation conditions (except the $Fe^{3+}$/P ratio).

*Table 1 $Fe^{3+}$/P ratio influence on efficiency of phosphorus removal ($Q_{ww}$ = 1.4 L/s, $m_{air,in}$ = 6.2 mglL)*

| $Fe^{3+}$/P (g/g) | P-tot removal efficiency (%) | P-$PO_4$ removal efficiency (%) | P-$PO_4$/P-tot ration in inflow wastewater |
|---|---|---|---|
| 1.7 | 34.7 | 71.9 | 0.73 |
| 2.6 | 51.2 | 83.2 | 0.78 |
| 5.0 | 52.4 | 93.2 | 0.71 |

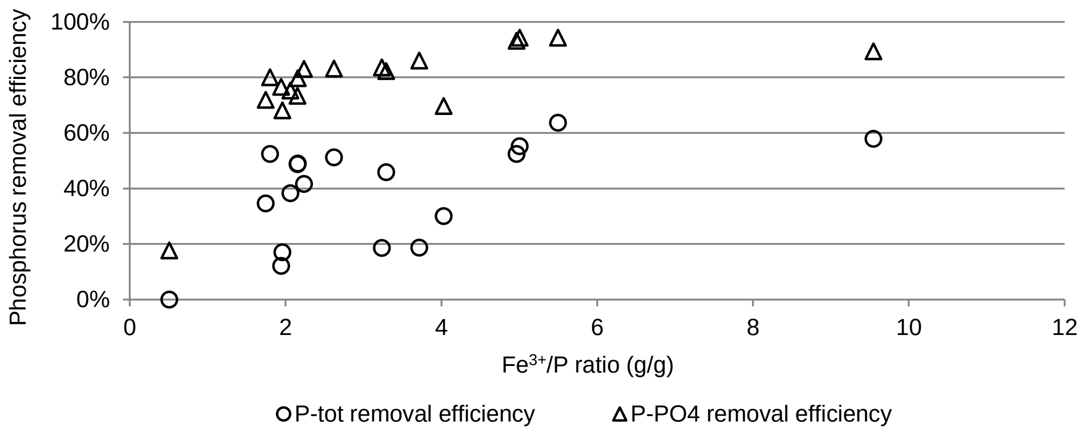


*Figure 3: Influence of $Fe^{3+}$/P ratio on phosphorus removal efficiency – all measurements*

Figure 3 shows the results of all measurements. The flow rate of purified wastewater ranges from 0.8 to 1.4 L/s, the specific air input ranges from 0 to 72.7 mg/L, the $Fe^{3+}$/P ratio ranges from 0.5 to 9.6 g/g. The most of the measurements ran at the $Fe^{3+}$/P ratio from 1.7 to 4 g/g and the efficiency of total phosphorus removal was approx. 45 % in this range. However, the increase of $Fe^{3+}$ dosage does not contribute significantly to increase of phosphorus removal efficiency. The $Fe^{3+}$/P ratio about 2 g/g seems to be optimal in case of a small concentration of phosphorus in purified wastewater. It is clear this parameter should always be monitored (followed by economic evaluation) at the testing operation of real units using this technology, because each application is specific.

### 3.2 Influence of specific air input on phosphorus removal efficiency

Biologically purified wastewater contains only a small concentration of phosphorus, so a small amount of precipitate is created during chemical precipitation. Figure 4 shows that the flotation zone and also a separation zone of the flotation tank is filled with air in a form of microbubbles and only thin layer of floating precipitate is formed. It was proven that the amount of air input affect the phosphorus removal efficiency only slightly (see Figure 5). The amount about 6 mg/L can be considered sufficient for the tested application.

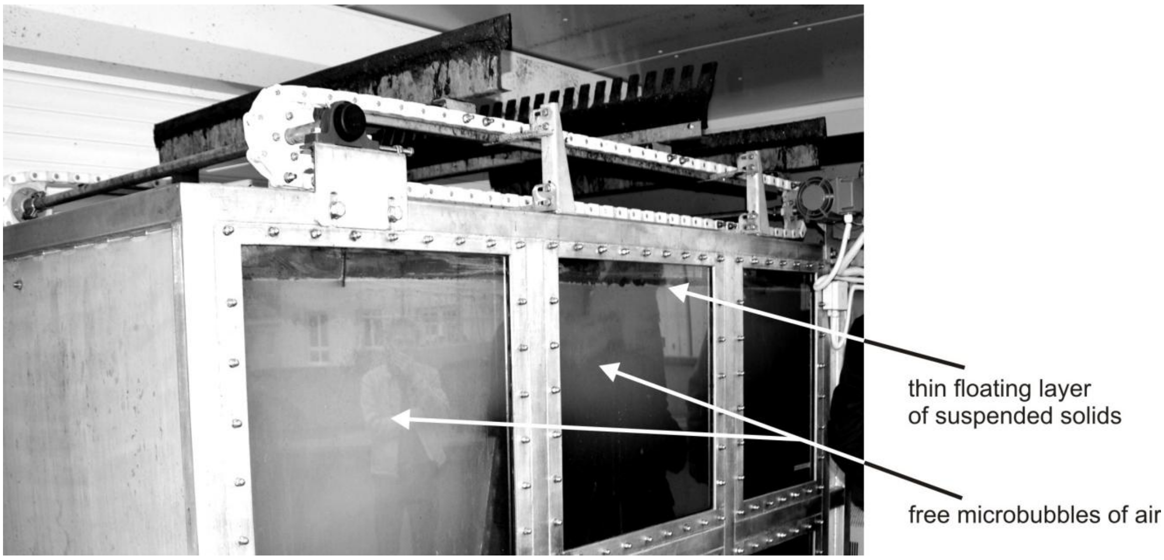


*Figure 4: Thin layer of precipitate in flotation tank*

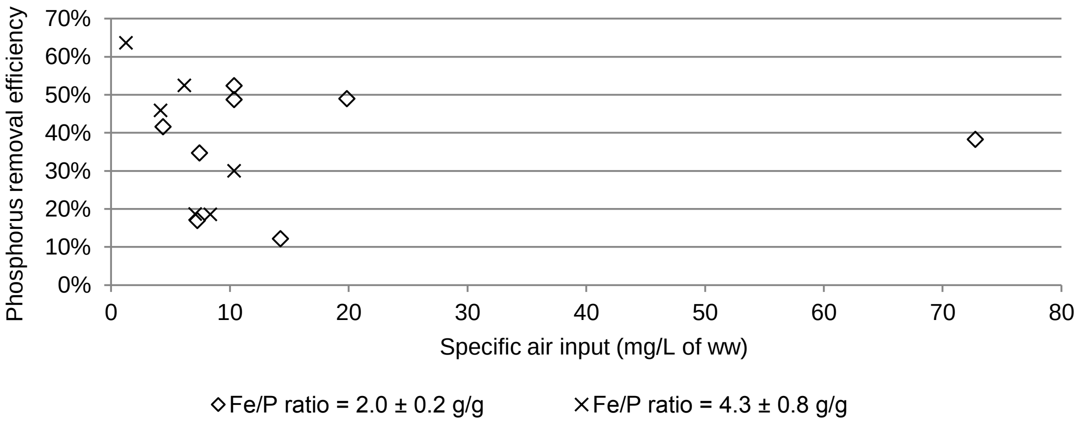


*Figure 5: Influence of specific air input on phosphorus removal efficiency – all measurements*

*Table 2 HRT influence on efficiency of phosphorus removal ($Q_{ww}$ = 0.8 L/s, $m_{air,in}$ = 10.4 mglL)*

| HTR (min) | P-tot removal efficiency (%) | $P\text{-}PO_4$ removal efficiency (%) | $Fe^{3+}$/P ratio (g/g) | $P\text{-}PO_4$/P-tot ration in inflow wastewater |
|---|---|---|---|---|
| 10 | 48.7 | 73.3 | 2.2 | 0.77 |
| 15 | 52.4 | 80.0 | 1.8 | 0.65 |
| 20 | 30.0 | 69.7 | 4.0 | 0.66 |

**3.3 Influence of hydraulic retention time in tank for slow mixing**
Chemical precipitation is influenced by a reaction time and approx. 20 min is recommended hydraulic retention time. Table 2 shows that the HRT does not affect the efficiency of phosphorus removal significantly, when it is higher than 10 min.

## 4. Conclusion

By the pilot scale tests it was verified that the technology of chemical precipitation and separation of suspension by dissolved air flotation is suitable to remove phosphorus from wastewaters with very low concentrations of total phosphorus. Dosing an appropriate amount of precipitant, a significant decrease of concentration (about 75 %) of phosphorus presented in the inorganic form was observed. It means decrease of total phosphorus concentration by 50 %. The optimum dose at low input concentrations of total phosphorus can be recommended approx. 2 g $Fe^{3+}$/g P. In case of increasing the dosage of $Fe^{3+}$ to about 5 g/g P, the inorganic phosphorus concentration decrease by 94 %, which means approx. 55 % decrease of total phosphorus concentration. Increasing the air fed in flotation unit had no positive effect as well as the longer hydraulic retention time. The amount about 6 mg/L and the HRT approx. 15 min can be considered sufficient for the tested application.

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