Optimisation of phosphate removal with coagulation in a small scale biological WWTP

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Abstract

Source-separated systems are mostly used on ships, planes and separate land areas. It caused the need of local wastewater treatment plants, specifically designed for blackwater treatment. This work observes the possibility of chemical improvement of small shipboard biological wastewater treatment plant (Ecomotive) for better phosphate removal from blackwater. There is considered possibility of usage and process conditions for different separation method: sedimentation and filtration. There was studied influence of coagulants and flocculants on the residual value of TSS, COD, TP and OP in water. On the basis of conducted experiments there was proposed a principal diagram of blackwater treatment process.

Keywords: blackwater, coagulation, phosphate removal, local WWTP.

Introduction

Modern approaches to water and wastewater treatment assume realization of sustainable development principles. Implementation of DESAR (decentralized sanitation and re-use) concept can be used for solving problems either poor, or rich countries (STOWA, 2005).

The main element of this concept is that wastewater streams are separated according to their degree and type of pollution and reuse potential of resources. Three main resources are considered: bio-energy (originated from transformation of organic material), nutrients (nitrogen, phosphorus as main nutrients but also potassium and sulphur) and water.

Generally, shipboard wastewaters can be divided into two streams: blackwater and greywater (including galley water, Sun et al., 2010). Vacuum toilets’ installation gave the opportunity to reduce the volume of wastewaters. The amount of flushing water is about 1-2 l (STOWA, 2005). Even though that obtained blackwater is highly concentrated it is still needs a lot of onboard space.

With a growing demand for renewable energy and decreasing availability of raw materials such as phosphate and (depending on the location) of water, blackwater is increasingly recognized as a source of raw materials (Zeeman et al., 2011).

Vacuum toilets and local WWTP are the halves of one system. Domestic wastewaters can also be divided into blackwater and greywater (Remy, 2010), therefore such systems can be used on the land as well. For example, they can be used in small separate settlements, in the railway stations, in dormitories etc.

High concentration of blackwater creates many problems for its purification on an existing installation, mainly due to the high content of hardly-biodegradable organic contaminants. System developed for the purification of mixed waste, did not give a satisfactory degree of purification of blackwater; processes of clogging and foaming increased risk of accidents.

Using of chemical treatment together with biological is one of the most common ways to enhance removal of phosphorous and suspended solids. According to literature search invention of chemical pre-treatment allows to decrease the organic load of biological step from about 60% to 15%.

Chemical treatment is a well known process but it is interesting to study the possibility of its implementation into small WWTPs. As the small treatment plants are vulnerable to external factors chemicals should make the biological processes more flexible.

At the same time addition of chemicals will change the pH of water and its content that will affect on the microorganisms in biological step and therefore biological treatment efficiency (Metcalt & Eddy, 1991). As well residual content of chemicals in water can be toxic for microorganisms, so it is necessary to check their influence.

According to these reasons it was suggested to develop a small shipboard installation for blackwater treatment. The study is conducted with support of both “Jets” and “Ecomotive” companies.

Therefore it was proposed to upgrade the existing biological wastewater treatment plant to ensure stable operation and increase the degree of purification blackwater from the major groups of impurities. But one of the main reasons is that a new station must be compact, reliable and work automatically.

The objectives of the research:

- to study if it is possible to enhance phosphate removal in compact biological WWTPs using common chemical pre-treatment;
- to study if dosages of chemicals are adequate comparing to the dosages on usual WWTPs;
- to study different separation methods.

Materials and methods

Materials

Inorganic coagulants used in the present work (ALS, PAX-18, PAX-33, PAX-XL60, PIX-313, PIX-318) are certified commercial products from Kemira (Finland). Organic flocculants (polyacrylamides FO 4240, FO 4290, FO 4290 SH, FO 4290 SSH, FO 4350 SSH) are commercial products from SNF Group (France).

Methods

To determine the type of coagulant and its dosage, type of flocculant and its dosage, order of their addition and process conditions the standard jar-test method was used. Besides that there was proposed the variation of this method – instead of sedimentation there was used filtration through the screens with the diameter of holes of 3 mm. These screens are standard and were adapted for blackwater treatment.

Jar test equipment consists of controller block and 6 1l beakers with mechanical stews. Controller block allows to set mixing parameters separately for each beaker.

Sedimentation jar-test includes 3 steps: fast mixing (60 s., 350 rpm), slow mixing (10 min, 30 rpm), sedimentation (20 min). Filtration jar-test also consist of 3 steps: fast mixing (60 s., 350 rpm), slow mixing (10 min if necessary, 30 rpm) and filtration.

8 samples are obtained as a result of one jar-test: 1 sample of well-mixed raw blackwater, 6 samples of water with different process conditions (as usual chemical dosage), and 1 reference blackwater sample (it undergoes sedimentation/filtration as others, but without chemicals).

Analyses

For treated and raw water pH was measured using a glass electrode pH meter after fast mixing step. After 20 minutes of sedimentation there was measured level of sludge. After the end of jar-test samples of water were taken for further analyses: Total Suspended Solids (TSS), Total Phosphorous (TP), Orthophosphates (OP), Chemical Oxygen Demand (COD and COD soluble). After filtration water was well-mixed before sampling. In most cases samples were taken from the top water layer at 25 mm depth.

TSS were determined according to standard methods using glass fiber filter disks GF/C 1.2 µm (APHA, 2005; SINTEF, 2004). The volume of filtered sample varied from 5 to 50 ml depending on visual observations.

TP was determined in the unfiltered samples using Hach Lange cuvette tests LCK350 and LCK349 according to standard methods (APHA, 2005). OP were determined in the filtered samples using Hach Lange cuvette tests LCK350 and LCK349 according to standard methods (APHA, 2005). As usual samples were diluted 5 to 50 times due to the high concentrations.

COD (CODs) was determined in the unfiltered (filtered) samples using Hach Lange cuvette tests LCK014 according to standard methods (APHA, 2005).

Results

The raw water is a blackwater taken from Jets™ vacuum toilets in Kaja student dormitories in Ås. It is assumed to be representational for the separate sewer systems both on land and on ships. The amount of flushing water is 1.2 liters. According to measurements blackwater is 10-20 times more concentrated than municipal wastewater. Blackwater is collected in the 300 l mixing tank and homogenized. Approximate characteristics of blackwater and typical domestic wastewater are shown in the Table 1.

Table 1 Blackwater characteristics

Parameter	Municipal water[1]	Mean and standard deviation	№ of samples
pH	7.0 – 8.0	8.50 ± 0.24	25
COD, g O_2/l	0.50 – 1.20	10.6 ± 1.2	25
CODs , g O_2/l	0.2 – 0.48	3.356 ± 0.3	4
TP, mg/l	6 – 25	162 ± 29	11
OP, mg/l	4 – 15	83 ± 12	8
TSS, g/l	0.25 – 0.6	5.9 ± 1.4	23

Inorganic coagulants

Addition of aluminium-based coagulants does not cause visual changes in flocs formation, but the amount of sludge increases with increasing of dosage (Fig. 1). Observed orthophosphate removal is not enough with the low dosages of coagulants, while using of higher dosages is impossible as the sludge becomes very volumetric and can fill almost all beaker's volume. That

[1] According to Henze, M., & Comeau, Y. (2008). Wastewater Characterization.

means that it is necessary to add flocculants to make sludge more compact and to increase OP and TSS removal.

Dosages of coagulants were taken so that the molar ratio was Me : TP = 0.7 – 2.0. According to wastewater treatment practice it should be from 2 to 4.

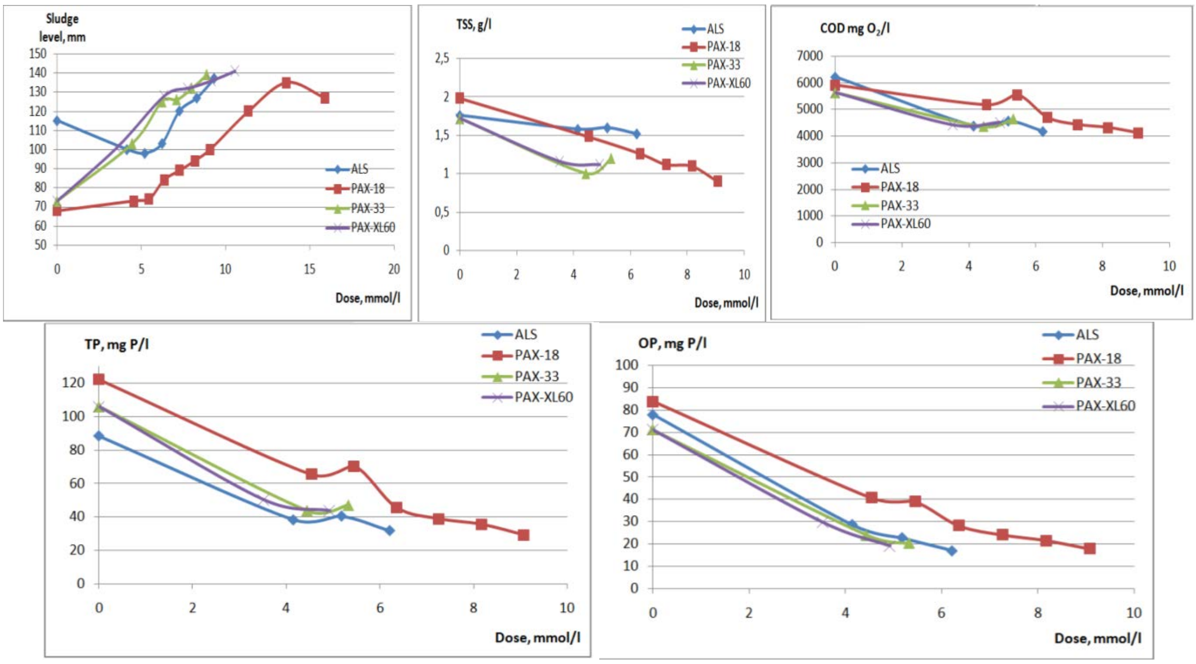


Figure 1 Results of aluminium-based coagulants' usage.

Even though that aluminium-based coagulants show better work at pH = 6.5-7.0 it was decided not to influence the pH level. First, experiments with pH-adjustment showed, that at pH ≤ 7.0 it is began gassing and partial sludge floating (Fig. 2). It is assumed that gassing caused by H_2S or CO_2 emissions. One part of sludge is settled to the bottom of the beaker, the other one lifts up to the top. So the top layer is a mixture of air bubbles and particles. Second, pH regulation means installation of additional equipment and additional volumes needed for chemicals.

Figure 2 Results of pH adjustment. From the left to the right pH: 5.5;6.0;6.5;7.0;7.5;8.0.

After addition of iron-based coagulants water becomes of deep black color (Fig. 3), which will cause failure in further photometric analysis. Moreover due to the sharp decrease of pH level it is observed gassing and partial sludge floating. Separation process is not observed that mean that these coagulants cannot be used for blackwater treatment.

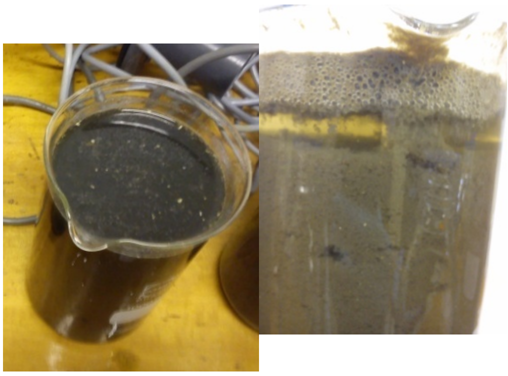
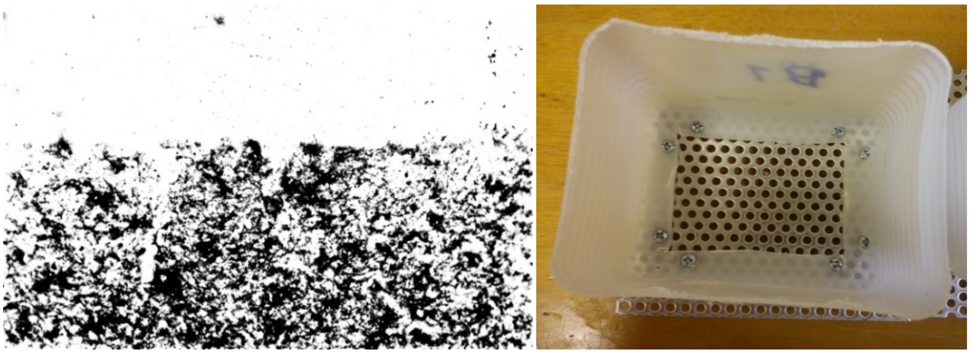


Figure 3 Usage of iron-based coagulants

Organic flocculants

Particles in wastewaters usually have negative charge, so it was decided to choose as flocculants cationic polyacrylamides. Together with paper in water they bind in very big flocs, creating some kind of matrix (Fig. 4a). This leads to the fact that sludge almost does not thicken during 20 minutes (sedimentation time). For these reasons it was proposed to use standard screens to separate sludge (Fig. 4b).



a b

Figure 4 Matrix created by addition of PAA into the blackwater (a). Image analysis was conducted by Nataliia Sivchenko, PhD candidate of IMT, NMBU. Laboratory form of screen, used for filtration (b)

Experiments showed that the more flocculant we add, the more TSS and COD removal. So the amount of flocculant mainly regulates by cost limitations and requirements for sludge and water composition.

Treatment efficiency of polyacrylamides of different molecular weight (FO 4290, FO 4290 SH, FO 4290 SSH) depends on the separation method. In sedimentation jar-tests the best results were obtained for polymer with lower molecular weight (FO 4290). Whereas in filtration jar-tests molecular weight of PAA does not affect significantly on the TSS or COD removal (Fig. 5).

It was found, that using high dosages of flocculant (>40 mg/l) we can change slow sedimentation for fast filtration. The difference between treatment efficiency for sedimentation and filtration decreases with the polymer dosage increase. Moreover it was discovered, that slow mixing time before filtration can be decreased to 0.5-1 min. So it is possible to "save" about 30 minutes (slow mixing and sedimentation).

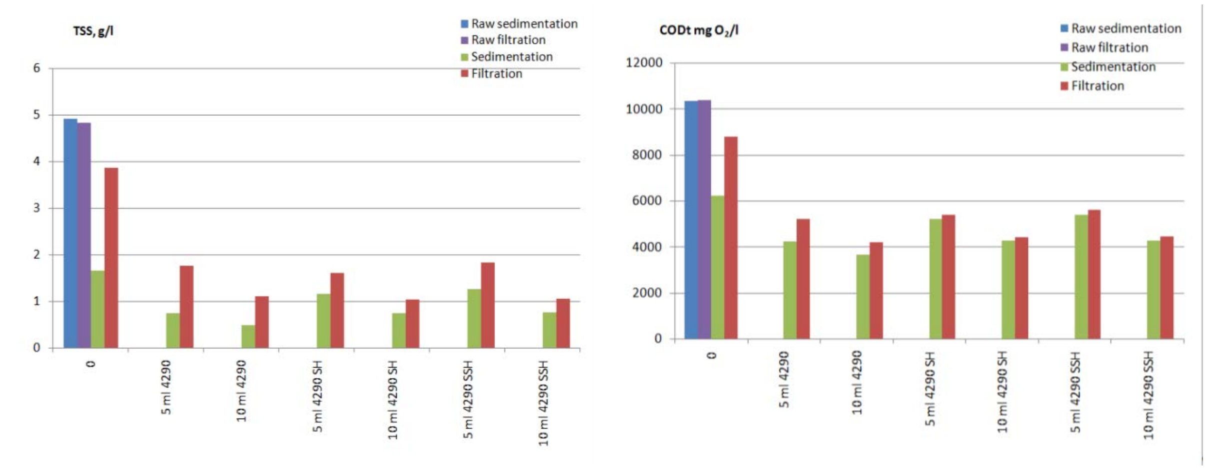


Figure 5 Values of TSS and COD for polymers of different molecular weight using sedimentation and filtration.

Coagulant and flocculant

Addition of both coagulant and flocculant provides better results. Coagulant binds orthophosphate ions, while flocculant enlarges particles and makes sludge more compact. Among different coagulants ALS in pair with FO 4290 (25 mg/l) showed incredible results in sedimentation jar-test when flocculant is added after coagulant: TSS removal for 99.2%, COD – 70.3%, TP – 98.4%, OP – 98.0%. (Fig. 6). At the same time if to compare dosages with usual dosages in WWTPs, it is seen that they are adequate (1.8 mol Al/ mol TP against 2-4 mol Al/ mol TP for WWTPs).

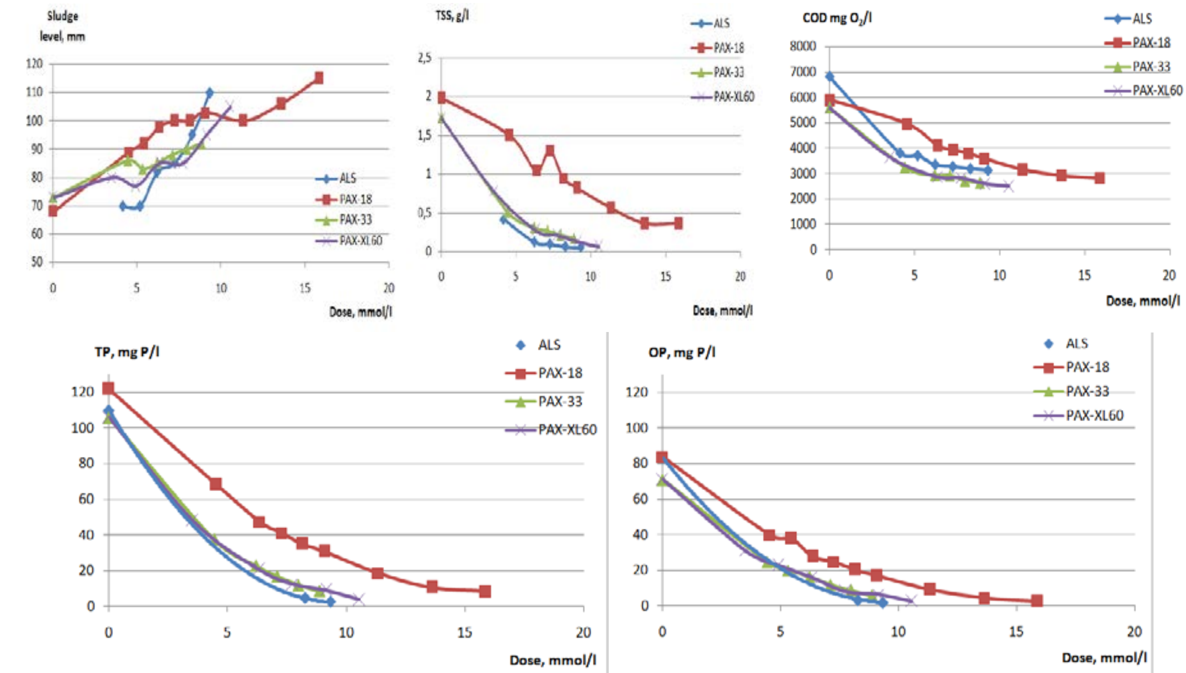


Figure 6 Results of addition both coagulant and flocculant FO4290 (25 mg/l).

Using filtration instead of sedimentation gives sufficiently lower results for TSS (51.0%), COD (45.7%) and TP (64.6%) (Fig. 7).Simultaneous addition of chemicals in sedimentation jar-test also decreases treatment efficiency for TSS, COD and TP to the meanings 94.4%, 66.6% and 93.6% correspondingly (Fig. 7).

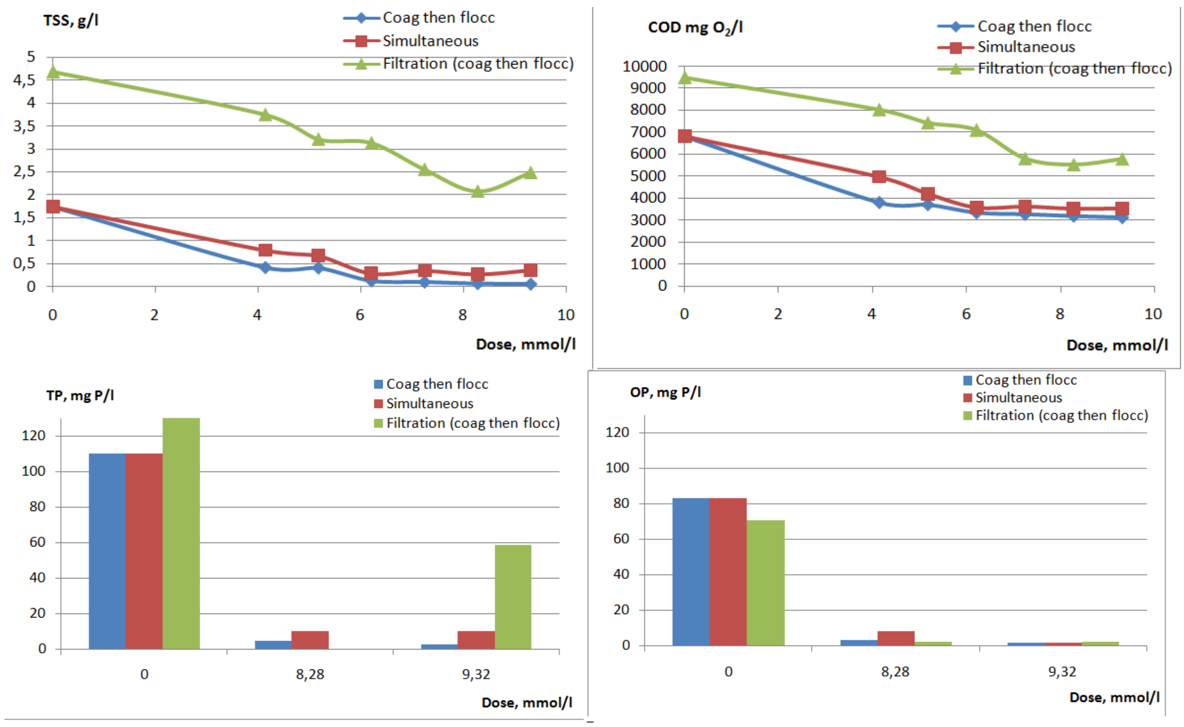


Figure 7 Comparison of results for simultaneous and sequential addition of chemicals with sedimentation, and for sedimentation and filtration for sequential addition of chemicals.

It is seen that OP removal also depends on the separation method and order of chemicals' addition, but for the high dosage of ALS (9.32 mmol Al/l) the results are quite similar.

The velocity of fast mixing does not affect on the treatment efficiency in sedimentation jar-tests with both coagulant and flocculant. Increasing time of fast mixing up to 40 sec will cause decreasing treatment efficiency.

On the basis of the results there was proposed a principle diagram of treatment process (Fig. 8).

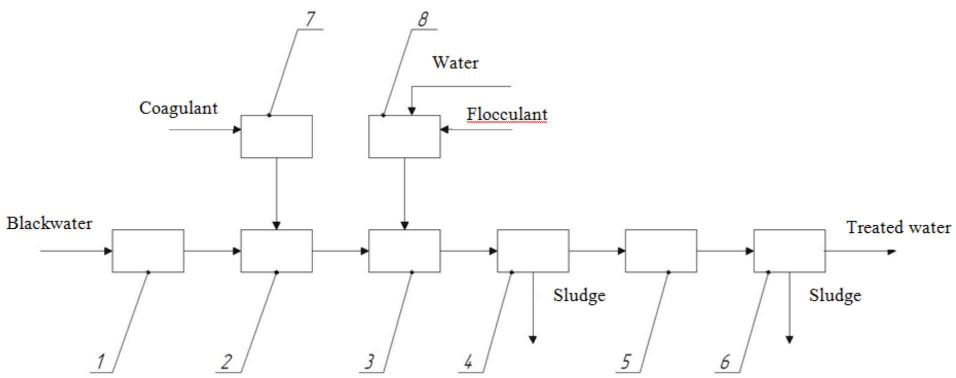


Figure 8 Principle diagram of blackwater treatment process. 1, 5 – holding tanks; 2, 3 – mixing tanks; 4 – separation step (sedimentation/filtration); 6 – biological treatment; 7, 8 – containers.

Conclusions

Conducted analysis gave the reasons to say that it is possible to use common chemical pre-treatment to enhance phosphate removal in compact biological WWTPs. It will help to decrease loading of biological step.

It is also necessary, that used coagulants are common and their dosages (relatively to the TSS/COD/TP/OP) are not exceed dosages for municipal wastewaters.

It is possible to use filtration instead of sedimentation due to the high size of flocs, created by polymer and paper in blackwater. And installation of screens may help to decrease total treatment time.

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