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Improvement of phosphorus removal in the wastewater treatment

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This research study is dedicated to sustainable use of backwash residual from groundwater treatment plants. A high concentration of phosphorus ranging from more than 12 mg/l was detected after primary sedimentation of domestic wastewater and cannot be removed with the existing biological reactors at wastewater treatment plants (Vilnius, Lithuania). Previous research results showed that the high levels of nitrogen compounds are also connected with phosphorus substances. A new reused material is presented in this article for the removal of phosphorus substances from wastewater by use of iron saturated backwash solids obtained from groundwater treatment plants. The treated wastewater quality increased during the treatment that used the 1 g/l dosage of backwash residual from groundwater treatment filters: phosphorus compounds concentration decreased by 98%. All results obtained from this research can be used with the background of sustainable development approach, when backwash residuals from gravitational filters can be collected and used for the removal of phosphorus compounds from domestic wastewater.

Key words: wastewater treatment, phosphorus compounds, iron compounds, reuse of backwash solids

INTRODUCTION

A conventional-type biological system is appropriate for use in any application in wastewater treatment, that would benefit from physical-chemical treatment including coagulation, flocculation and settling (Dauknys et al., 2009). It can be applied to both domestic wastewater and some industrial wastewaters where either better performance or cost reduction is desired (Ebeling et al., 2003). It is suited to treat difficult waters such as rapidly fluctuating sources or extreme conditions (Vabolienė et al., 2007; Xiaolian et al., 2006). The process consistently displays efficient removals from wastewaters containing suspended solids, organic compounds, ammonia and other undesirable water contaminants (Li et al., 2008). At the wastewater treatment works in the European Union (Lithuania since 2004), aerated wastewater has been treated in biological reactors with activated sludge for pollutants removal. However, the existing treatment equipment cannot ensure high quality of treated wastewater. The total phosphorus concentration was found to be up to 12 mg/l and was without sufficient losses after primary treatment at Vilnius wastewater treatment plants. The total phosphorus concentration should be 1 mg/l following the new Lithuanian requirement. The phosphorus concentration in primary treated wastewater was between 10.20–12.8 mg/l and does not either follow the untreated wastewater quantity. The treated wastewater used as outlet water for the Neris River (the second biggest river) also has unquestionable requirements and strict permissions.

Conventional wastewater clarification processes primarily involve the destabilization and subsequent removal of colloidal suspended solid materials that are not readily removed by gravitation alone (Galarneau, Ronald, 1997). These suspended

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materials can be natural or synthetic organic or inorganic compounds, microorganisms. The balance of colloidal suspended materials is connected to a net negative surface charge that moves individual particles to keep distance from each other and remains in suspension in most natural waters. Usually highly charged ionic coagulants such as alum ($Al_2(SO_4)_3$), ferric chloride ($FeCl_s$), ferric sulfate ($Fe_2(SO_4)_3$), lime or some polymers are added to destroy a net reduction in the repulsive forces between the removed compounds (Banu et al., 2008). This method, named coagulation, requires additional space for chemical sludge formation, removal and disposal issues. Usually the same operators are responsible for wastewater collections, treatment and drinking water supply, e. g. the biggest Lithuanian company JSC 'Vilniaus Vandenys'. When looking for sustainable solutions, we found out that iron saturated pressed backwash residual from groundwater treatment filters could be useful for the removal of phosphorus compounds from wastewater (Cordray, 2008; Moelants et al., 2011). Data on the quality of groundwater from the Lithuanian groundwater treatment plants equipped with air-scour backwash was collected during the last decade by the Water Company JSC 'Vilniaus Vandenys' showing typical values as follows: pH 7.33–7.52; conductivity ~514 µS/cm; Fe_{total} 0.3–2.86 mg/L; NH_4^+ 0.19–0.59 mg/L; Mn 0.13–0.19 mg/L; Na ~13 mg/L; Ca 57.8–74.5 mg/L; and dry residual – 306 mg/L.

Groundwater from these sources is supplied to the drinking water system after use of iron removal equipment and after that the water is disinfected. Iron removal plants were built following traditional conventional designs and technology, that used a simple aeration method of groundwater and filtration of open gravitational filters with quartz sand filter media (0.6–1.5 mm particle size and 1 600 mm high) (Valentukeviciene, 2008; 2009).

The drinking water treatment at Antaviliai (Lithuania) has a useful residual and pressed cake resulting from a large quantity of iron substances in groundwater, indicated by a high level of the total iron concentrations. The high level of iron existing in groundwater which can be removed by iron-removing filters is of great interest for possible reuse options. The treatment of drinking water after iron removal is connected to the presence of biological substances (Valentukeviciene, Jankauskas, 2004). The high level of iron content (till 40% of total dry residual) in backwash pressed cake is also the result of the organic substance content. Iron removal should therefore follow an organic substance removal process, e. g. backwash (Šaltenienė; Prentkovskis, 2004).

The aim of this article is to present an experimental research of a new wastewater treatment method with fewer amounts of chemicals, when groundwater treatment residual is used for the phosphorus compounds removal.

MATERIALS AND METHODS

A pilot-sized experimental plant was built at Vilnius Gediminas Technical University using the filter equipment that was located in the laboratory following the description in the article by Fytianos et al., 1998. Batch reactors (6 units, 1 L volume each) were used at the laboratory by inserting mechanical stirrers for the continuous mixing. The proposed method for wastewater treatment was investigated at this plant from December 2013 to May 2014.

Some wastewater quality (Table 1) and technological parameters were determined for the controll and for the evaluation of technological processes during the experiment as follows: total iron concentration, mg/l; manganese concentration, mg/l; orthophosphates concentrations, mg/L; filtration rate, m/h; pressed residual dosage, mg/l. Merck systems Aqua-quant tests and standard methods were used for the determination of iron, manganese, ammonium and phosphorus concentrations (LST EN ISO 15681-1:2005). The color and turbidity were determined by using standard methods. Data of the experimental investigation was statistically calculated from the registered analyses. The concentration of phosphorus substances was measured 11 times in supplied wastewater, in the taps of filters and in filtered wastewater. Average concentration at typical points is

$$\overline{c} = \frac{1}{n}\sum_{i=1}^{k} c_i m_i , \quad (1)$$

where c_i is the concentration of substances at typical points, m_i is the probability at recurrence of concentration; n is the number of days; k is the number of different values of concentration. There were calculated the average concentrations of substances mentioned above in the characteristical point. The standard statistical estimation error of the arithmetic average was approximatly 12%. Wastewater for both experiments was collected every previous day and then refrigerated. Average characteristics of wastewater used for the all experiments are presented in Table 1.

Table 1. **Average characteristics of wastewater used for the batch and gravitational filtration experiments**

Phosphates after primary sedimentation (PO_4-P), mg/l	12.0 ± 2.0
Phosphates after biological treatment (PO_4-P), mg/l	2.0 ± 0.04
pH	7.40 ± 0.10
T, °C	18.5 ± 1.0

During the experimental research, untreated wastewater was supplied to the water-supply pipeline and connected to the reactor and pilot sized filter. The reactor construction was influenced by regular contact time (by volume changing) and depended on the technological needs. Iron saturated backwash residual, obtained from the top of an open gravitational filter (Fig. 1), was added to the reactor. Iron saturated residual was obtained from Antaviliai (Vilnius, Lithuania) because it was easy to collect useful amount of liquid samples from open gravitational filters (Fig. 1) and pressed material (Fig. 2) from a press-filter. It is difficult to obtain backwash residual from other places because usually pressure filters with close loop systems are in use at water treatment works.

All contents of the reactor's volume were mixed by a laboratory mixer without the sedimentation of added residual. The water and iron saturated residual mixture from the reactor was supplied to the sedimentation equipment during the sedimentation process of the used sediments. The sedimentation equipment was constructed from six plastic containers of 1 L volume. Wastewater after sedimentation was taken to analyses during the removal of phosphorus and other substances.

Iron compounds in the groundwater of Antaviliai (Vilnius, Lithuania) water works partially has high iron content and for this reason there is a useful backwash residual formation from particles separated of the groundwater.

The filter media was the same residual as that mentioned above, obtained from the pressed backwash residual cake from the press-filter (Fig. 2),

Fig. 1. Liquid backwash residual on the top of open gravitational filter (Antaviliai, Lithuania)

Fig. 2. Press-filter producing pressed backwash residual cake (Antaviliai, Lithuania)

the height used was 500 mm and the size of the residual particles was 0.6 to 1.5 mm (Kim et al., 2012).

The experimental equipment resulted in a comparison of the treatments of the residual obtained from pressed backwash residual cake from the press-filter (Fig. 2) and untreated aerated filtration by using filter media and filtration technology, when the same untreated wastewater was supplied to the reactor and after aeration of the pilot size filter. Taps for the water sampling were equipped to the pilot size filter column at the water outlet. The equipment in the untreated wastewater supply pipelines and the filtrated water outlet pipeline and the water flow were measured by a volume method. All experiments were repeated 3 times with similar conditions at the above-mentioned laboratory.

RESULTS AND DISCUSSION

The phosphorus removal efficiency was acceptable according to the applied conditions and so the wastewater treatment parameters were changed: the dosage of residual was increased up to 5 g/l and the filtration rate was decreased to 3 m/h. The removal percentage of phosphorus and its decrease can be seen in the experimental data shown in Figs. 3 and 4. Iron saturated residual dosages were held constant through the beginning of each spike addition until the phosphorus concentration of the clarified water decreased and stabilized. Residual dosages were then slightly adjusted to bring the clarified wastewater phosphorus concentration back into the target range following optimization (Wang et al., 2005.

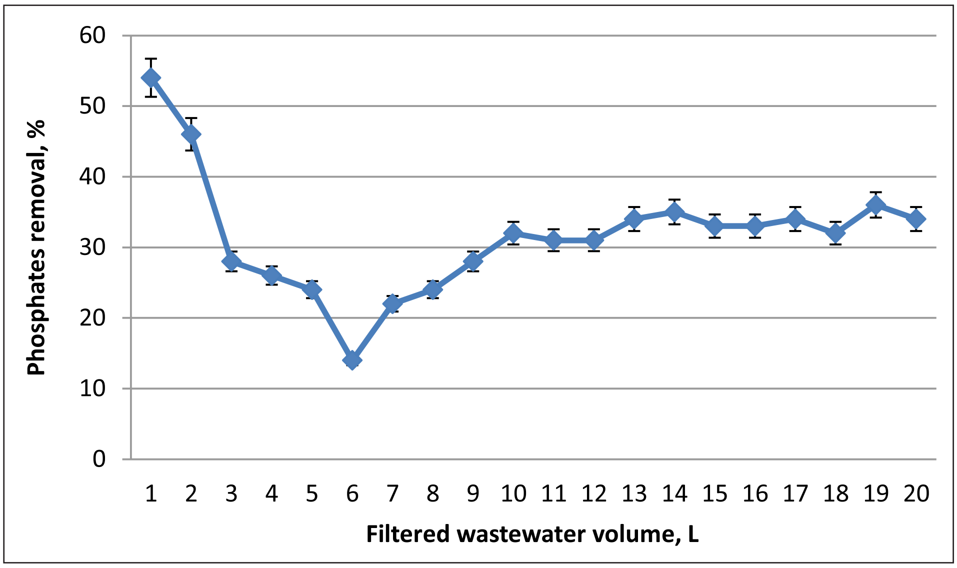

Fig. 3. Phosphates removal using wastewater filtration through granulated backwash residual

This test illustrates the overall stability of the wastewater treatment method in handling increases in the initial wastewater phosphorus concentration. Stable treatment was achieved within approximately one hydraulic retention time (15 minutes) of adjustment. This performance makes the process with adding iron saturated residual sufficient for treatment facilities that experience events related to changes in wastewater quality.

The facility produces higher quality clarified wastewater than it was a previously possible with elimination of the iron and alum usage. Pilot testing data show similar or better treatment results at up to 55% reductions in chemical usage as compared to existing conventional facilities. The combination of efficient mixing and enhanced filtration with iron saturated residual allows wastewater treatment to provide effective removal of phosphorus.

Phosphorus removal was obtained down to 2 mg/l from 15 mg/1 influent concentration. Likewise, wastewater phosphorus as high as 12 mg/1 was reduced to less than 2 mg/1 in the filtered wastewater (Table 2). As stated, these results were achieved without the addition of chemical

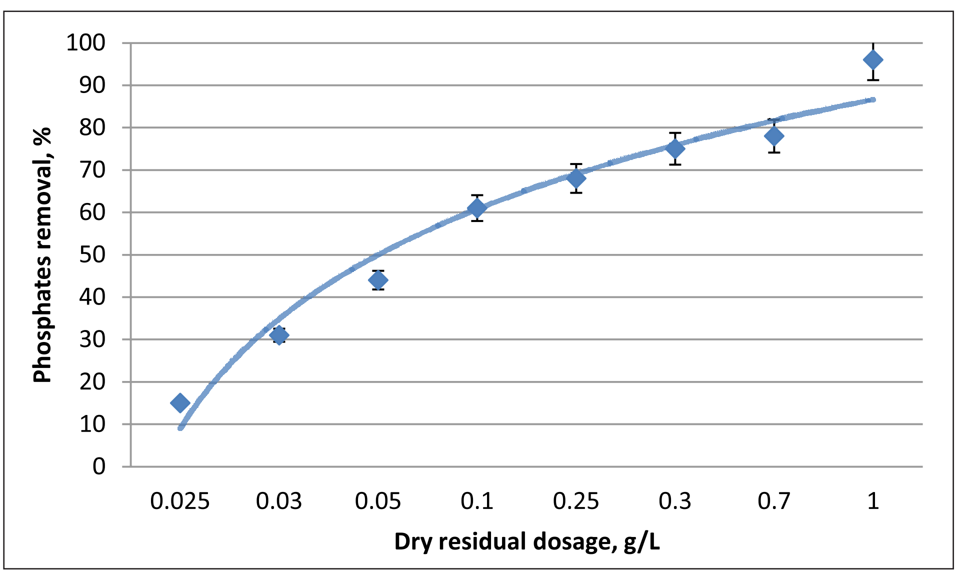

Fig. 4. Phosphates removal from domestic wastewater using backwash residual in batch test

Table 2. **Wastewater mixing run with iron saturated residual in the batch reactors**

	Mixing batch results				
Mixing run, min	5	10	15	20	25
Phosphates removal, %	51	55.5	61	61	61
Residual phosphates (PO_4-P) concentration, mg/L	6.00 ± 0.04	5.50 ± 0.04	5.00 ± 0.04	5.00 ± 0.04	5.00 ± 0.04
pH	7.48 ± 0.01	7.50 ± 0.01	7.50 ± 0.01	7.51 ± 0.01	7.50 ± 0.01

coagulants. The results from Table 2 show that the optimal batch reactor contact time with iron saturated residual is 15 min of the untreated wastewater with the iron content approximately 40%, using a pilot scaled mixer. The phosphorus removal was 61% at the sedimentation stage, and phosphorus removal was till 55% at the filtration stage.

Table 3 shows a comparison of the results from conventional treatment plants and the results from iron saturated residual pilot studies while running on the same wastewater in parallel studies. Similar results were obtained from some articles about the same wastewater treatment experiments (Banu et al., 2008; Cordray, 2008; Kim et al., 2012).

Some additional elements Fe, Ca, Mg, S, Ti, As, Cd, Co, Cr, Cu, Hg, Sb, Ni, Pb, Zn and Se were measured in conventional residuals (ferrous sulphate heptahydrate, digested sludge with iron chloride and iron (III) chloride (PIX-118)) from wastewater treatment plants and iron saturated backwash residual from the Antaviliai Water Treatment Plant (Table 3). In Table 3 results are shown from the samples taken from different wastewater treatment plants, and backwash residual was taken from backwash liquid and press filter cake.

The biggest iron content more than 35% was obtained in iron saturated backwash residual (liquid and pressed cake respectively) from the Antaviliai Water Treatment Plant. Adding of backwash residual will produce better quality of the settled wastewater than that the wastewater treated with usual materials. Fewer amounts of commercially available materials will be used for the same results of phosphorus removal from domestic wastewater. All heavy metals were obtained in quantities below the requirements for the toxic and / or dangerous materials.

All obtained results show acceptable removal efficiencies of phosphorus compounds from a variety

Table 3. **Additional elements measured in conventional residuals from wastewater treatment plants and iron saturated backwash residuals from Antaviliai water treatment plant**

Elements, %	Residuals of conventional treatment			Backwash residuals		Abs. Error, %
	Ferrous sulphate heptahydrate	Digested sludge (with iron chloride)	Iron (III) chloride (PIX-118)	Liquid residual	Pressed cake	
Fe	19.5	1.73	11.6	38.18	35.37	0.02
Ca	0.3	2.9	n. a.	4.951	4.603	0.006
Mg	0.7	0.77	n. a.	0.200	0.223	0.005
S	12.1	1.19	n. a.	0.1829	0.2114	0.0005
Ti	0.25	n. a.	n. a.	0.1153	0.1283	0.0038
As	<0.001	0.0054	n. a.	0.00246	0.00107	0.00011
Cd	<0.001	0.0075	<0.007	<0.0002	<0.0002	n. a.
Co	0.061	0.041	n. a.	0.00138	0.00106	0.00033
Cr	0.011	0.037	0.027	0.0091	0.00768	0.00083
Cu	0.003	0.565	0.002	0.002	0.0014	0.00018
Hg	<0.001	0.0062	<0.005	<0.0001	<0.0001	n. a.
Sb	<0.001	n. a.	n. a.	<0.0003	<0.0003	n. a.
Ni	0.045	0.22	0.023	0.00199	0.00127	0.00137
Pb	0.006	0.19	0.002	0.00365	0.00298	0.00337
Zn	0.025	0.607	0.029	0.01226	0.00252	0.00013
Se	<0.001	n. a.	n. a.	<0.00005	<0.00005	n. a.

n. a. – not applied by detection device.

of wastewater compositions for iron saturated residual pilot studies performed in the laboratory over the last experimental research period.

The highest wastewater quality was obtained with the pilot scaled filter, i. e. aerated wastewater after treatment with backwash residual and filtration. Only some part of residual phosphorus 1.8 mg/l was found in filtrated wastewater (phosphorus concentration in untreated water was up to 15 mg/l). The time of filtration rate was long, and pressure losses after 90 hours were not increasing significantly.

In this experiment the concentration of phosphorus decreased to 2 mg/l using the batch test. The concentration of phosphorus compounds of the filtered wastewater was less than 1 mg/l.

The treated wastewater quality increased during the treatment that used the 1 g/l dosage of backwash residual from groundwater treatment filters: the concentration of phosphorus compounds decreased 98%.

CONCLUSIONS

The researched method differs from conventional clarification in that it provides backwash residual from groundwater treatment filters as a coagulating agent in the flocculation process step. The residual serves several important stages in the wastewater purification process:

1) High specific surface area to the volume ratio of the backwash residual particles serves as a background for flock formation;

2) Backwash residual particles promote the accumulation of suspended materials and result in the formation of large stable flocks;

3) Relatively high specific gravity of the backwash residual serves as a background for the formation of high-density flocks;

4) High total iron concentration within the wastewater purification process effectively improves the effects of changes in the domestic wastewater quality.

Together, these factors provide a process that is reliably efficient in the treatment of domestic wastewaters, stable with changes in domestic wastewater quality, and relatively easy to operate and optimize.

Overall, the use of backwash residual results in the development of sedimentation flocks that are significantly denser and heavier than the flocks from conventional sedimentation processes.

The advantages of iron saturated backwash residual enhanced flocculation provide for consistently high quality clarified under a variety of treatment conditions. The researched method offers stable operation and performance with significant variations in domestic wastewater quality.

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FOSFORO ŠALINIMO TOBULINIMAS NUOTEKŲ VALYKLOJE

Santrauka

Straipsnyje nagrinėjamos požeminio vandens ruošimo paplavų darnaus panaudojimo galimybės. 12 mg/l viršijančios fosforo koncentracijos buvo nustatytos Vilniaus (Lietuva) buitinių nuotekų sudėtyje po pirminio nusodinimo ir šiuo metu taikomais biologinio valymo metodais jos negali būti efektyviai sumažintos nuotekų valyklose. Ankstesnių tyrimų rezultatai parodė, kad padidėjusios fosforo junginių koncentracijos lemia didesnes azoto junginių koncentracijas. Šiame straipsnyje pateikiami nauji eksperimentinių tyrimų rezultatai, kurie demonstruoja efektyvaus fosforo junginių šalinimo iš nuotekų galimybes panaudojant geležies prisotintas paplavas. Tyrimo metu nustatyta, kad valomų buitinių nuotekų kokybė pagerėjo, kai valymo procese buvo panaudotos požeminio vandens ruošimo filtrų paplavos (fosforo junginių koncentracija vandenyje sumažėjo 98 %). Visi šio tyrimo metu gauti rezultatai gali būti sėkmingai taikomi darnaus vystymosi tikslams, kai atvirųjų filtrų paplavos surenkamos ir panaudojamos buitinių nuotekų valyklose fosforo junginiams šalinti.

Raktažodžiai: nuotekų valymas, fosforo junginiai, geležies junginiai, filtro plovimo paplavų panaudojimas