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Preliminary Investigation of Primary Sludge Hydrolysis

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Abstract. One of reasons of non-effective biological nutrient removal from wastewater is lack of readily biodegradable organic matter. This problem could be solved by application of sludge hydrolysis process. The conditions for hydrolysis of primary sludge could be created performing the recirculation of the primary sludge and ensuring the required sludge retention time. In the period of preliminary investigation, the following conditions were created in the primary sedimentation tank of Vitebsk WWTP: average sludge recirculation was 4.8 % of the inlet flowrate to the sedimentation tank and average SRT was 5 days. Obtained results showed that hydrolysis process allowed improving the ratio between organic matter and nutrients in wastewater.

Keywords: primary sludge hydrolysis, SRT, volatile solids, COD, BOD_5, ammonium nitrogen, phosphate phosphorus.

Conference topic: Water engineering

Introduction

The levels of total nitrogen (N_{tot}) and total phosphorus (P_{tot}) should remain as low as possible in effluent to natural water bodies in order to avoid eutrophication process of surface waters (Ali, Gupta 2013). Modern wastewater biological treatment technologies are not always able to ensure the required concentrations of N_{tot} and P_{tot} in treated wastewater in case of insufficient level of readily biodegradable organic matter (Ali, Gupta 2013; Aivasidis *et al.* 2011; Henze *et al.* 2008). Microorganisms use organic and biogenic substances at a certain ratio which is BOD: N_{tot} : P_{tot} = 100 : 5 : 1 (Mulkerrins *et al.* 2004; Houweling *et al.* 2010). Wastewater, however, contains the excess of nutrients and the aforementioned ratio can be BOD: N_{tot} : P_{tot} = 100 : 18±29 : 5.5±0.5. In order to ensure the necessary removal of nutrients from wastewater, an additional source of readily biodegradable organic matter is necessary. It can be an external source of carbon, such as ethanol, methanol or sludge generated in the course of wastewater treatment process. The external carbon source increases the costs of maintenance of treatment process; therefore, a focus should be on the sludge as the source of organic matter.

Readily biodegradable organic pollutants usually account for 10–35 % of total COD. Up to 56 % of total COD forms a share of slowly degradable carbon resources which cannot be directly absorbed by microorganisms. When wastewater or sludge remains in treatment plants for a longer period of time and under the influence of non-cellular ferments, the hydrolysis products are generated and can be fermented to volatile fatty acids (VFAs). These acids are used by the majority of microorganisms present in active sludge (Tremblay *et al.* 2005). According to scientific literature, the hydrolysis of primary sludge can reduce the residual concentrations of N_{tot} and P_{tot} in effluent (Mulkerrins *et al.* 2004; Ahn and Speece 2006; Bouzas*et al*. 2007; Ucisik and Henze 2008). The application of hydrolysis process results in the increase of the content of biodegradable organic matter allowing to correct BOD: N_{tot} : P_{tot} ratio in wastewater and, thus, to ensure the necessary effectiveness of the treatment of wastewater (Ucisik, Henze 2008). Hydrolysis of organic matter should take place before wastewater passes to the biological treatment process (Yuan, Oleszkiewicz 2010; Zurzolo *et al.* 2016). In larger treatment plants (> 20 thousand m^3/day) primary sedimentation tanks are usually installed before bioreactors which can be fitted for the hydrolysis process (Rabinowitz 2014). The conditions necessary for the hydrolysis of primary sludge can be ensured by installing primary sludge recirculation in sedimentation tanks and by keeping sludge in them for a certain period of time. In each specific case, a complex of factors is present, therefore, the experimental tests are necessary. The aim of this work was to form the conditions for the hydrolysis of primary sludge in the sedimentation tank and to find out how the composition of treated wastewater and primary sludge varies as a result of hydrolysis.

Methodology

The preliminary experimental tests were conducted under the industrial conditions in Vitebsk wastewater treatment plant. Two primary sedimentation tanks marked as No. 1 and No. 4 were selected for the tests (Fig. 1). The diameter of the first sedimentation tank – 28 m, the other – 30 m. The effective depth of both sedimentation tanks – 3.4 m. The ordinary wastewater sedimentation process was performed in one of these sedimentation tanks (No. 1), while in the other (No. 4) – the equipment for the circulation of sludge for the hydrolysis was installed. The equipment consisted of 3 pumps with Q = 4.0 l/s in each where H = 4.0 m and a supply pipe (Fig. 1). The number of pumps and their supplied discharge was chosen to ensure that sludge circulation would account for 4–5% of the debit of wastewater supplied to sedimentation tank. The height of pump installation from the bottom of sedimentation tank – 0.2 m, the distance from the edge of sedimentation tank – 0.2 m. The pumps were operating 24 h/day.

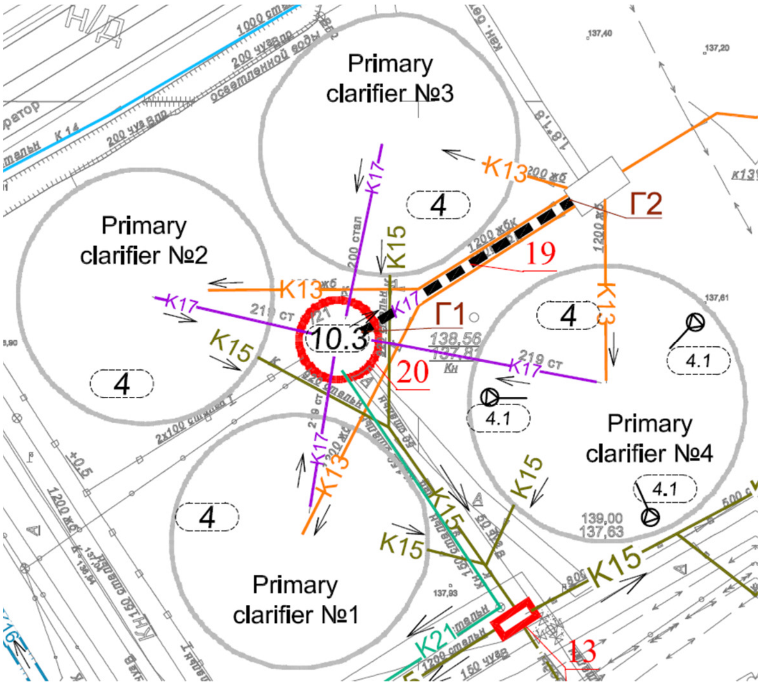

Fig. 1. Fragment of WWTP plan with primary sedimentation tanks: 4 – primary sedimentation tanks, 4.1 – pump for primary sludge hydrolysis, 10.3 – pumping station of primary sludge

Fig. 2. Photo of primary sedimentation tanks applied for investigation: in the left side the clarifier No 4 with equipment for sludge recirculation, in the right side the clarifier No 1 operating in normal settling regime

Duration of preliminary tests – 1.5 month. The first four weeks of the experiment were dedicated to the adaptation of hydrolysis process, therefore, the samples were not taken during this period. Later, the momentary samples of wastewater and sludge were taken on every business day at the same time of the day. The samples of wastewater were taken before the primary sedimentation tanks and after the primary sedimentation tanks No. 1 and No. 4, the samples of sludge – from primary sedimentation tanks No. 1 and No. 4, the sample of removed sludge. In addition to sampling, other measurements were taken, i. e. the level of sludge in tested sedimentation tanks, duration and amount of removed primary sludge, levels of wastewater discharged from primary sedimentation tanks in the overflow channels at the moment of sampling. The latter levels allowed to determine the proportion of distribution of the flow between sedimentation tanks. The daily discharge of the wastewater treatment plant was recorded during the research which was measured with ultrasonic flow meter *DNEPR 7* (tolerance – 2 %) in a pipe of the diameter of 1,200 mm between grit chambers and primary sedimentation tanks.

The hourly flowrate to each sedimentation tank was calculated according to the average day flowrate and according to the proportion of distribution of flow between sedimentation tanks determined according to the measurement results. The calculation of the hourly flowrate per each sedimentation tank allowed to determine its surface load. Hydraulic surface load was calculated according to equation:

$$q = \frac{Q_h}{A}\ , \text{m}^3/\text{m}^2/\text{h}; \quad (1)$$

where: Q_h – hourly flowrate to the sedimentation tank, m^3/h; A – surface area of the sedimentation tank, m^2.

Sludge retention time was calculated according to equation:

$$\text{SRT} = \frac{V_d \cdot a_{ave.}}{Q_d \cdot a_d}, \text{d}; \quad (2)$$

where: V_d – volume of sludge in the bottom of sedimentation tank, m^3; a_{ave} – average sludge concentration in the bottom of sedimentation tank, kg DS/m^3; Q_d – flowrate of removed primary sludge from the sedimentation tank, m^3/d; a_d – concentration of removed primary sludge from the sedimentation tank, kg DS/m^3.

Composition of wastewater pollutants (COD, BOD_5, NH_4^+–N –, PO_4^{3-}–P concentrations), sludge composition (dry matter, ash content) and pH were tested in the laboratory of the wastewater treatment plant, temperature and oxidation–reduction potential (ORP) were measured at the sampling place. Standard analytic methods were used for the determination of the COD, BOD, ammonium nitrogen, phosphate phosphorus, dry solids, volatile solids content and pH. The measurements were taken with metrologically tested devices in the laboratory.

During the research, it was selected to maintain the hydraulic surface load at the level of no more than 1.6 $m^3/m^2/h$, the SRT in the sedimentation tank – between 4–7 days on the average. If the abovementioned values of hydraulic load are selected, the rainwater causes no influence on the work of the sedimentation tank. The values of the SRT were selected in view of the information provided in literature sources that the process of hydrolysis of the primary sludge should last for 3–8 days (Bouzas *et al*. 2007; Li *et al.* 2009; Rabinowitz 2014).

Results

During the invetigation, the daily flowrate to Vitebsk WWTP varied from 64,635 m^3/d up to 75,270 m^3/d with the average value of 69,323 m^3/d. The results of measurement revealed that the primary sedimentation tank No 1 received 27% of wastewater flow, whereas the sedimentation tank No. 4 with the hydrolysis process received 31% of the flow. Thus, the hourly average flowrate to the latter sedimentation tank varied between 835 m^3/h and 972 m^3/h.

It is selected to maintain sludge recirculation of 4–5% of inlet flowrate to the sedimentation tank. According to the results of investigation the sludge recirculation varied from 4.4% up to 5.2% with average value of 4.8%.

The values of hydraulic load of sedimentation tanks No 1 and No 2 were analogous. They varied from 1.2 $m^3/m^2/h$ to 1.4 $m^3/m^2/h$ with average value of 1.27 $m^3/m^2/h$ and met the selected condition to maintain the hydraulic surface load not higher than 1.6 $m^3/m^2/h$. The values of the SRT kept in the sedimentation tank No. 1 varied from 4.1 d to 6.5 d with the average value of 5.0 d. Thus, the maintained values of SRT were also in compliance with the selected limits of values of SRT.

The temperature of wastewater varied from 14.8°C to 15.6°C during the tests with the average value of 15.2 °C. The pH of wastewater in the inlet to sedimentation tanks varied from 7.6 to 8.0, whereas the average value was 7.8. In the outlet of sedimentation tank No. 1 the average pH value decreased by 1.3% and was equal to 7.7, whereas in the outlet of sedimentation tank No. 4, where the hydrolysis of sludge was performed, the average pH value decreased by 5.1% and amounted to 7.4.

Values of wastewater pollution in the inlet to and outlet from the primary sedimentation tanks are provided in Table 1 and the values of ratios of parameters are presented in Table 2.

Table 1. Values of wastewater pollution in the inlet to and outlet from the sedimentation tanks

Parameter	In inlet to sedimentation tanks			In outlet of sedimentation tank No 1			In outlet of sedimentation tank No 4		
	Min	Average	Max	Min	Average	Max	Min	Average	Max
COD, mg/l	621	787	923	538	650	770	680	780	904
BOD_5, mg/l	230	291	390	230	267	300	280	326	372
PO_4^{3-}–P, mg/l	3.4	5.1	11.0	4,4	4.9	5.3	4.1	5.2	6.0
NH_4^+–N, mg/l	37	57	74	24	54	79	27	53	74

Table 2. Values of ratios of pollution parameters

Ratio of parameters	In inlet to sedimentation tanks	In outlet of sedimentation tank No 1	In outlet of sedimentation tank No 4
COD/BOD_5	2,7	2,4	2,4
BOD_5/PO_4^{3-}–P	57	54	63
BOD_5/NH_4^+–N	5,1	4,9	6,2

Average COD concentration decreased by 17% and the average BOD_5 concentration decreased by 8% in the outlet of sedimentation tank No 1 (Table 1). Whereas the average COD concentration remained the same practically and the BOD_5 concentration increased by 12% in the outlet of sedimentation tank No 1 with hydrolysis process. Comparing the effluent quality in the outlet of sedimentation tanks No 1 and No 4, it could be stated that the COD concentration was higher by 20% and BOD_5 concentration was higher by 22% the in the outlet of the sedimentation tank No 4. Therefore, the hydrolysis process generated 155 mg/l of COD and 59 mg/l of BOD_5 in average.

Average concentration of PO_4^{3-}–P increased by 2.0% in the outlet of sedimentation tank No 4, whereas it decreased by 4.0% in the outlet of sedimentation tank No 1. The results show that the hydrolysis process had no significant influence on the variation of concentration of phosphate phosphorus therefore the value of BDS_5/PO_4^{3-}–P ratio increased from 57 in the inlet to sedimentation tank up to 63 in the outlet of sedimentation tank. This is led to the increase by 10% of the value of BDS_5/PO_4^{3-}–P ratio. Comparing with the value of BDS_5/PO_4^{3-}–P ratio in the outlet of sedimentation tank without hydrolysis process the ratio increased by 14 % in the outlet of sedimentation tank with hydrolysis process.

Average concentration of NH_4^+–N increased by 7.0% and 5.3% in the outlet of sedimentation tank No 4 and No 1 respectively. The results show that the hydrolysis process had no significant influence on the variation of concentration of ammonium nitrogen therefore the value of BDS_5/ NH_4^+–N ratio increased from 5.1 in the inlet to sedimentation tank up to 6.2 in the outlet of sedimentation tank. This is led to the increase by 18% of the value of BDS_5/ NH_4^+–N ratio. Comparing with the value of BDS_5/ NH_4^+–N ratio in the outlet of sedimentation tank without hydrolysis process the ratio increased by 21% in the outlet of sedimentation tank with hydrolysis process.

Values of parameters of primary sludge in the investigated sedimentation tanks are presented in Table 3.

Table 3. Values of parameters of primary sludge

Parameter	Sedimentation tank No 1			Sedimentation tank No 4		
	Min	Average	Max	Min	Average	Max
Dry solids (kg DS/m^3)	13,0	21,8	30,5	21,0	33,6	51,0
Volatile solids (%)	81,8	82,8	84,0	77,2	77,6	78,2
ORP (mV)	–346	–254	–180	–376	–293	–220

Due to selected SRT value of 5 days, the amount of sludge was higher in the sedimentation tank No 4 than in the sedimentation tank No 1. Results show that the average sludge concentration was higher by 54% in the sedimentation tank No 4 than in the tank No 1 and they were equal to 33.6 kg DS/m^3 and 21.8 kg DS/m^3 respectively (Table 3). The organic matter is degraded to simpler compounds during hydrolysis process therefore the amount of organic matter reduces in the sludge. Investigation showed that the content of volatile solids as part of DS decreased from 4.6% up to 7.9% with average value of 6.3% comparing with case when the hydrolysis process was not applied.

The ORP indicates the degradation degree of the organic matter. It is higher when the ORP values are lower. The results show that the average value of ORP was lower by 15% in the sludge of sedimentation tank No 4 comparing with sludge in the tank No 1 (Table 3).

The further investigation will be performed in order to define the relationship between the sludge concentration and the sludge level in the sedimentation tank, as well to define the optimum SRT value, the minimum acceptable ORP value for the control of the hydrolysis process.

Conclusions

1. In the period of preliminary investigation, the suitable conditions for hydrolysis process were created in the sedimentation tank of wastewater treatment plant: average sludge recirculation was 4.8% of the inlet flowrate to the sedimentation tank, average hydraulic load was 1.27 $m^3/m^2/h$, SRT – 5 d, temperature – 15 ºC, pH – 7.4.
2. Under the abovementioned conditions the COD concentration increased by 20% and BOD_5 concentration increased by 22%. Due to hydrolysis of sludge it is generated 155 mg/l of COD and 59 mg/l of BOD_5 in average.
3. Performing the hydrolysis process in the primary sedimentation tank the values of BOD_5/PO_4^{3-}–P and BOD_5/NH_4^+–N ratios were improved that is important for more efficient nutrient removal in biological way.

Comparing with the sedimentation process without hydrolysis the mentioned ratios increased by 14% and 21% respectively.

4. The volatile solids content as a part of DS decreased by 6.3% in average due to degradation of organic matter during the hydrolysis process.
5. Performing the hydrolysis process, it is important to control pH value in wastewater as it decreased by 5.1% during the investigation.

Contribution

R. Dauknys declares involvement in conception and design of the work, participation in field measures. A. Mažeikienė declares involvement in analysis, interpretation of data. A. Haluza declares involvement in acquisition and interpretation of data. I. Halauniou declares involvement in conception of the work. V.Yushchenko declares participation in field measures, involvement in interpretation of data.

Disclosure statement

The authors declare that they do not have any competing financial, professional, or personal interests from other parties.

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