

Research of Wastewater Tertiary Treatment

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Abstract. The tertiary wastewater treatment experiment was performed on the experimental stand which was installed in a wastewater treatment plant and which consisted of three filters of the diameter of 380 mm with a non-submerged media. Biologically treated wastewater was constantly supplied to these filters. Tertiary wastewater treatment process was aggravated due to low temperature of wastewater (6 °C) and high fluctuations of load according to individual pollutants – the difference between the minimum and maximum values ranged from 3 to 10 times. The productivity of removal of pollutants according to individual contamination rates reached 8 to 43%.

Keywords: tertiary treatment, biological filtration, loading by pollutants.

Conference topic: Water engineering.

Introduction

The territory of Lithuania is attributed to eutrophication-sensitive area where more stringent requirements are applied for the discharge of wastewater (Council Directive...1991). In agglomerations with PE exceeding 10,000, wastewater needs in practice be treated in tertiary treatment step. Tertiary wastewater treatment is also applied in smaller wastewater treatment plants when the required degree of treatment is not achieved during primary and secondary treatment or where the concentrations of discharged wastewater pollutants exceed the allowable values of concentrations of pollutants according to the effect on the reception facility.

During the tertiary treatment, the productivity of elimination of pollutants that were eliminated during the main treatment step is even more increased (Smith and Scott, 2005). The suspended solids can be eliminated from wastewater by using filters with synthetic, geotextile, broken glass, palm pulp media materials (Horan and Lowe 2007, Riahi *et al.* 2009, Tchobanoglous 2003). It has been noted that the particles of filter media should be large enough to prevent the filters from clogging and also fine enough to hold the suspended solids (Tchobanoglous 2003). Mechanical filters must be washed as the quality of treated wastewater deteriorates over time and leads to the increase in pressure losses. In case of need to eliminate organic and biogenic materials during the tertiary wastewater treatment, the facilities operating on the basis of biological filtration can be used. In trickling filters, the pollutants are eliminated by using microorganisms attached to the filter media during the biological filtration (Tchobanoglous 2003; Kirjanova 2014). Biological removal of pollutants can be performed together with mechanical filtration (Payraudeau *et al.* 2001; Pujol *et al.* 1998). The microorganisms growing on a biofilm formed on the surface of filter media oxidise the organic pollutants present in the wastewater to carbon dioxide and water and form a new biomass in this way. The microorganisms absorb nitrogen and phosphorus compounds from wastewater. It happens on the external layer of biofilm of the thickness of 0.1–0.2 mm.

The media of trickling filters should be inexpensive and durable and should have a large surface area and high porosity to avoid filter clogging and to ensure good air circulation. The modular media of plastic or stone is usually used in filters (Daigger and Boltz 2011, Pearce and Jarvis 2009, Tchobanoglous 2003). The porosity of stone media is low, therefore, it leads to a worse air circulation and results in a higher likelihood of clogging (Harisson and Daigger 1987). Other materials are not almost used in trickling filters. The possibilities of the use of tires, artificial grass cover, nylon sponges and charcoal as media for trickling filters have been tested (Mondal and Warith 2008; Lekang and Kleppe 2000; Moulick *et al.* 2011), however, these materials are not used in practice. The most recent research suggests that the best solution is the biological filtration through mineral wool under the conditions of periodical supply of wastewater (Kirjanova 2014).

The experiments described in this work are performed by conducting a constant wastewater supply to biofiltration facilities. The aim of work was to find out whether biological filtration with mineral wool media and porolon media can be applied in tertiary treatment step in medium-sized wastewater treatment plants.

Methodology

Experimental equipment

The experimental stand was installed in a technical room of a medium-sized ($2,000 < PE < 10,000$) wastewater treatment plant in order to ensure continuous supply of wastewater. During the experiment, the air temperature of the room was approx. $5\text{ }^{\circ}\text{C}$. The experimental stand used for tertiary wastewater treatment experiment consisted of three trickling filters with non-submerged media, a pump for wastewater supply to filters, a tank for the collection of filtered wastewater and a pump for the return of filtered wastewater to a reservoir (Fig. 1).

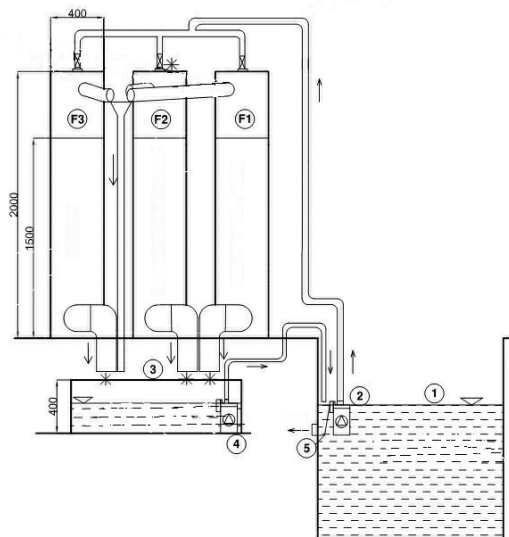


Fig.1. A conceptual scheme of filters for wastewater tertiary treatment: F1, F2, F3 – filters, 1 – reservoir of effluent from the biological treatment, 2 – wastewater supply pump, 3 – effluent collection tank, 4 – pump for wastewater supply to the outlet, 5 – channel of wastewater outlet, * sampling point

During the experiment, biologically treated wastewater was supplied from reservoir (1) by pump (2) and via pressure pipe and distributed to three filters. The wastewater was distributed on filter media by directing the flow to the flow distribution plate. Filtered through the non-submerged media, the wastewater was collected in the container (3) and then supplied with pump (4) to the outlet (5) in the reservoir of treated waste (1). The diameters of each filter – 380 mm, the height – 2,000 mm. The supporting layer of gravel of 150 mm was installed in all filters. An even surface load – $0.07\text{ m}^3/\text{m}^2/\text{min}$. was maintained in each filter (Tchobanoglous *et al.* 2014).

The volume load by pollutants was calculated using the formula:

$$A_i = \frac{C_i \cdot Q_{d.aver.}}{V}, \text{ kg/m}^3/\text{d}; \quad (1)$$

where: C_i – wastewater pollution according to one of the indicators, mg/l ; $Q_{d.aver.}$ – average daily wastewater flowrate, m^3/d ; V – volume of filter media, m^3 .

Media of filters

During the test, the rock wool cubes *Growcube* of the size of $10 \times 10 \times 10\text{ mm}$ were used to fill the filter F1. The properties of this media: high water-absorption level – $92 \pm 2\%$, good air permeability and the ability to maintain its structure and shape over time, density of cubes – 46.4 kg/m^3 . Due to these properties, the media is useful not only for mechanic filtration to eliminate suspended solids, but also for biological filtration.

In the second filter F2, the mineral wool *Paroc WAS 35* cut into the cubes of the size of $30 \times 30 \times 30\text{ mm}$ was used for media. The properties of this media: resistant to water, water absorption level – $60 \pm 2\%$, ability to maintain its structure and shape over time, density of cubes – 46.5 kg/m^3 .

Porolon was selected for the media of the filter F3. It was cut into the cubes of the size of $30 \times 30 \times 30\text{ mm}$. The properties of this media: level of water absorption – $26 \pm 2\%$, changes of shape in case of getting wet, density of cubes – 13.4 kg/m^3 . Furthermore, porolon is not expensive and easier to acquire. It was selected in order to compare the materials of different density.

The height of dry media is selected of 1,500 mm as it is recommended for trickling filters (Tchobanoglous *et al.* 2014).

Sampling and chemical analysis

Duration of the test was 4.5 months. The first two weeks of the experiment were dedicated to the adaptation of bio-filtration process; therefore, the samples were not taken during this period. Later, the momentary samples of wastewater were taken at four points once per week and at the same time of the day: one before the filters and one after each filter (Fig. 1).

COD, BOD₇, SS, NO₃⁻-N, NH₄⁺-N and PO₄³⁻-P concentrations, pH and temperature were determined in the wastewater. The samples were tested in the laboratory of the Department of Water Engineering of the VGTU and Ecological Maintenance Laboratory of UAB "Grinda". Each sample was tested three times and the average values of results were provided.

The temperature of wastewater was measured with *SevenGo pro SG6* meter at the time of sampling, pH value was determined potentiometrically (LST EN ISO 10523:2012) by using a microprocessor *pH-211* for measuring.

SS concentration was assessed gravimetrically by filtering wastewater through the glass fibre filter (LAND 46–2007) and weighed by KERN *ABJ 220-4M* type electronic laboratory balance.

COD was determined titrimetrically. Bichromatic oxidation was performed with thermoreactor *Eco-6* and the excess of oxidant was titrated according to LAND 83–2006.

BOD₇ was determined by using oximeter *ino Lab OXI-730* according to LAND 47–1:2007.

Ammonium nitrogen was determined spectrophotometrically according to LAND 38–2000. Nitrate nitrogen was tested by *Spectroquant* tests. Concentrations of analytes were specified spectrometrically (LST ISO 7890-3:1998). Phosphate phosphorus was determined spectrometrically (LST EN ISO 6878:2004). Measurements were conducted with *Genesys 10 UV-Vis* spectrophotometer.

Results and discussion

The research was carried out in the winter period under the conditions of varying outdoor temperature. During the 17-week long research period, the outdoor air temperature dropped down to –25 °C on multiple occasions. This resulted in several malfunctions of the supply of wastewater to filters, because the pipes of the experimental stand were not insulated. The situation in wastewater treatment plant was also unfavourable; the treatment of wastewater took place only in two sections of biological treatment instead of three, because one was under reconstructions. The functioning of filters was disordered both by hydraulic load and pollution load due to the increase in the amount of treated wastewater. In the course of research, the supply of wastewater to filters was terminated several times for a day due to the increase in the concentration of pollutants according to SS in wastewater supplied to filters more than twice. The temperature of wastewater passing to the experimental stand varied from 6 °C to 12 °C. The variation of wastewater temperatures and filter loads according to BOD₇ is provided in Fig. 2.

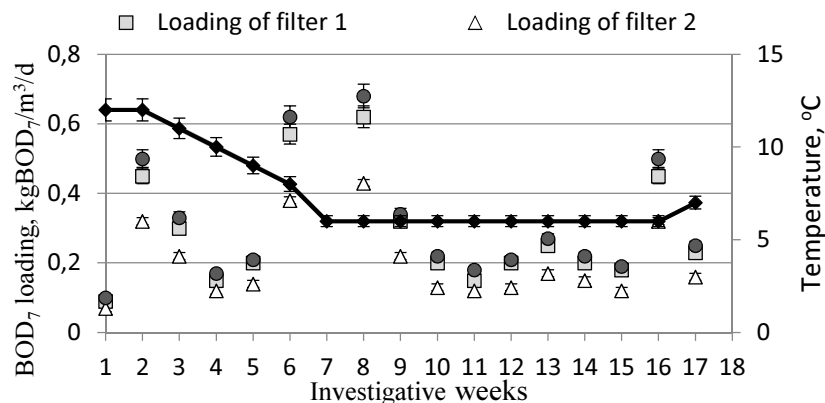


Fig.2. BOD₇ loading of filters and wastewater temperature

Fig. 2 shows that the temperature of wastewater was decreasing from the first week of the research and stabilised at 6 °C after 7 weeks. Such temperature of wastewater was kept practically the whole time of the research. The average pH of the entering wastewater was 7.4 during the experiment. The average value of this index did not change after the filters or varied only by 1.3% and was 7.4 after the first filter with mineral wool *Growcube* and 7.5 after the second filter with *Paroc WAS 35* media as well as after the third filter with porolon media. In view of the fact that the average pH of entering and discharged wastewater was similar during the entire period of experiment, it can be stated that pH had no influence on the removal of pollutants from wastewater.

After starting to supply the wastewater to filters, the decrease in the heights of *Growcube* media and porolon media was observed – by 30% and 37% respectively. The comparison of the loads of the media of all three filters

according to BOD₇ revealed that the maximum average load of 0.32 kg BOD₇/m³/d was in filter F3 with porolon media due to the decreased volume of the media, whereas the minimum average load of 0.2 kg BOD₇/m³/d was determined in filter F2 with mineral wool *Paroc WAS 35* media. In filter F1, the maximum volumetric load with BOD₇ amounted to 0.61 kg BOD₇/m³/d during the entire period of experiment, in filter F2 – 0.43 kg BOD₇/m³/d, and in filter F3 – 0.68 kg BOD₇/m³/d (Fig. 2). Thus, the maximum value of volumetric load with BOD₇ was by 7 times higher than the minimum one in different filters.

The loads of filters with SS, NH₄⁺-N, NO₃⁻-N, PO₄³⁻-P are provided in Table 1.

Table 1. Loads of filters according to SS, NH₄⁺-N, NO₃⁻-N, PO₄³⁻-P

Load, kg/m ³ /d	Filter 1			Filter 2			Filter 3		
	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.
SM	0.15±0.1	0.48±0.2	1.09±0.3	0.14±0.1	0.36±0.1	0.75±0.2	0.18±0.1	0.6±0.2	1.18±0.3
NH ₄ ⁺ -N	0.16±0.1	0.50±0.2	2.05±0.4	0.02±0.1	0.43±0.1	2.0±0.4	0.3±0.1	0.67±0.2	2.3±0.4
NO ₃ ⁻ -N	0.04±0.1	0.25±0.1	0.58±0.1	0.03±0.1	0.17±0.1	0.41±0.1	0.04±0.1	0.27±0.1	0.64±0.2
PO ₄ ³⁻ -P	0.12±0.1	0.2±0.1	0.35±0.1	0.07±0.1	0.15±0.1	0.25±0.1	0.13±0.1	0.24±0.1	0.39±0.1

Table 1 suggests that the loads of filters with SS, NH₄⁺-N, NO₃⁻-N, PO₄³⁻-P demonstrated significant variation during the experiment, i.e. the maximum value of load with SS was by 6.8–7.1 times higher than the minimum in different filters. The loads of ammonium nitrogen, nitrate nitrogen and phosphate phosphorus also varied by 3-12 times.

The average concentrations of wastewater pollutants in the samples before and after the filters are provided in Fig. 3. In the outlets of all filters, the concentrations of pollutants were lower than in the wastewater supplied to filters. The effectiveness of removal of pollutants was 8-40%. The most effective removal of pollutants from the wastewater was that of SS in all filters. The effectiveness of SS removal of filter 1 reached 43%, while in filters 2 and 3 – 33%. The filters managed to catch the suspended solids due to mechanical and biological processes. In view of the fact that the effectiveness of removal of organic substances after biological treatment is related to the elimination of SS as the major part of SS consists of active sludge, the obtained results suggest that the organic pollutants and SS were removed most productively by filter F1 with mineral wool *Growcube* media. After the comparison with tests of mineral wool *Growcube* performed by other researchers (Kirjanova 2014) under the conditions of periodical supply of waste to the filters (the effectiveness of elimination of BOD₇ pollutants reached 61–84%; the effectiveness of elimination of COD pollutants reached 40–60%; SS – 50–69%), the currently obtained effectiveness of elimination of pollutants was by 2–4 times lower. In case of constant supply of wastewater, the elimination of pollutants was negatively influenced by the instability of load with pollutants. In other words, the increased SS concentration in wastewater supplied to filters increased the possibility of clogging in the filters. Unstable loads were basically conditioned by malfunctions of biological process in the wastewater treatment plant.

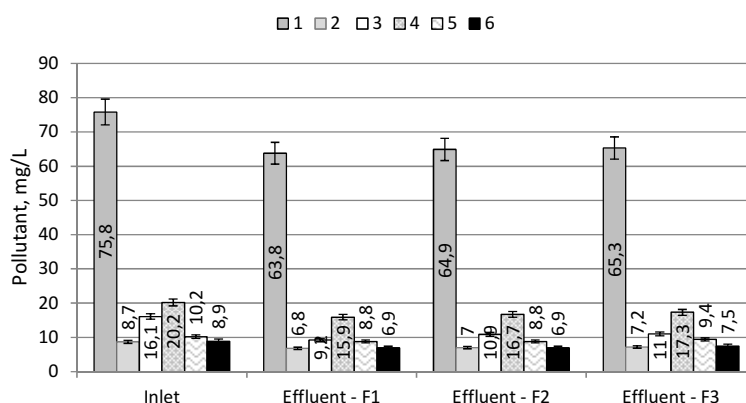


Fig.3. Average concentrations of wastewater pollutants in the samples before and after the filters. Where: 1 – COD, 2 – BOD₇, 3 – SS, 4 – NH₄⁺-N, 5 – NO₃⁻-N, 6 – PO₄³⁻-P

The elimination of ammonium nitrogen demonstrated the effectiveness of 14–21% in all three filters. The best ammonium nitrogen elimination results (21%) were demonstrated by filter F1 with mineral wool *Growcube* media,

the worst – by filter F3 with porolon media. The achievement of a better result of nitrification was prevented by low wastewater temperature (6 °C, Fig. 2), as well as as the load with organic substances which was 3-times higher than the load recommended for the nitrification process in the literature sources (up to 0.17 kg BOD₇/m³/d, van der Akker *et al.* 2010b, Mofokeng *et al.* 2009).

Nitrate nitrogen was eliminated with 8–13% effectiveness. The best results were achieved by using the first media (*Growcube*). Denitrification process depends on the availability of coal, concentration of nitrates and nitrites in wastewater, wastewater temperature, concentration of oxygen and the amount of denitrification bacteria. Robertson (2010) found out that with nitrate nitrogen concentration being 3–50 mg/L, the concentration of nitrate nitrogen is not a factor limiting denitrification. In case of this experiment, the concentration of nitrate nitrogen reached the average of 9–10 mg/L in wastewater before the filters and was sufficient for denitrification. Low wastewater temperature (6°C, Fig. 2) as well as availability of coal prevented from the achievement of a better denitrification result.

The effectiveness of removal of phosphate phosphorus was 22 to 16%. The best results were achieved by using *Growcube* media and *Paroc WAS 35* media. Some phosphates were absorbed by biofilm microorganisms, some of them were mechanically caught together with SS in the media of filters.

The summarised results suggest that high effectiveness of elimination of pollutants was not achieved under the conditions of the experiments. It can be concluded that the application of biological filtration is not reliable when wastewater is constantly supplied to the filters under industrial conditions. The norms of contamination of wastewater discharged to the natural environment set to the medium-sized wastewater treatment plant (2,000 < PE < 10,000) were 2 mg P/L, 20 mg N/L. According to Fig. 3, the sum of concentrations of ammonium nitrogen and nitrate nitrogen in the outlets of all 3 filters was higher than the allowable total nitrogen concentration of 20 mg/L (30.4 mg/L; 24.7 mg/L; 26.7 mg/L respectively). The concentrations of phosphate phosphorus in the outlets of all filters were also higher than the allowable total phosphorus concentration of 2 mg/L (8.9 mg/L, 7.5 mg/L respectively). Thus, the application of tertiary wastewater treatment with investigated media has not proved to be adequate under the conditions of the experiment.

Conclusions

1. When maintaining constant surface load during the experiment (0.07 m³/m²/min), the loads of filters according to individual pollutants (COD, BOD₇, SS, NH₄⁺-N, NO₃⁻-N, PO₄³⁻-P) varied from 3 to 10 times.
2. The effectiveness of elimination of pollutants was conditioned by the fluctuations of loads according to the analysed pollutants; according to SS it was 43%, according to COD, BOD₇, NH₄⁺-N, PO₄³⁻-P – 14–25%, according to NO₃⁻-N – 8–13%. In terms of elimination of pollutants, slightly more effective than others appeared to be (1–5%) *Growcube* media.
3. In order to ensure necessary effectiveness of elimination of pollutants when applying filters with analysed media, it is recommended to solve the issue of variation of load with pollutants by increasing the reliability of the work of previous wastewater treatment steps.

Contribution

R. Dauknyš declares involvement in conception and design of the work, participation in field measures. A. Mažeikienė declares involvement in analysis, 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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