

## START-UP OF TRICKLING FILTERS USING NOVEL FILTER MEDIUM UNDER LOW TEMPERATURE CONDITIONS

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**Abstract.** Start-up of three pilot scale trickling filters (3.05 m in height and 0.6 m (1 TF), 0.8 m (2 TF) and 1.0 m (3 TF) in diameter) using the stonewool substrate medium at low wastewater temperature (2.5–8.5 °C) was investigated over a period of 123 days. The start-up of the trickling filters was performed without any special inoculation, only by feeding the raw wastewater to the trickling filters. Low temperature did not have an impact on the removal of SS and BOD<sub>7</sub>: the removal of these substances reached steady state in two weeks of operation, while nitrification was influenced by low temperature. Nitrification was first observed on day 90 of operation, the highest recorded value of nitrification efficiency was only 40.9% and the nitrification performance have not stabilized by day 123 of the experiment. Nevertheless, the further increase in nitrification is expected as the experiment is still continued. Throughout the experimental period the efficiency of SS removal was 96.9±2.4% in 2 TF and 97.5±1.9% in 3 TF with SS loading to the filters up to 1 kg SS/m<sup>3</sup> of stonewool medium/d. BOD<sub>7</sub> removal efficiency was 94.3±4.0% in 2 TF and 94.9±3.3% in 3 TF with BOD<sub>7</sub> loading to the filters up to 0.8 kg BOD<sub>7</sub>/m<sup>3</sup> of stonewool medium/d. SS and BOD<sub>7</sub> removal efficiencies of 1 TF filter were 96.1±1.9% and 92.6±3.3% respectively until the clogging of the filter on day 90 of operation.

**Keywords:** trickling filter, start-up, filter media, stonewool, nitrification, wastewater, treatment, low temperature.

### 1. Introduction

Trickling filters have been used for biological wastewater treatment since 1890s. A trickling filter is a fixed-film reactor with nonsubmerged medium over which wastewater is distributed. Treatment of wastewater occurs when wastewater passes through the biofilm attached to the medium. Trickling filters are used for organic matter removal, simultaneous organic matter removal and nitrification as well as tertiary nitrification. Their advantages over the activated sludge process are less energy requirement, less need for equipment maintenance, simpler operation (Bitter 1994, Tchobanoglous *et al.* 2003).

Before the stable operation, a trickling filter undergoes a start-up stage during which the biofilm develops. Many factors affect the start-up as well as the performance of nitrifying fixed-film reactors such as the hydraulic residence time, the reactor's hydrodynamics, the concentration of pollutants in the influent, etc. (Mann *et al.* 1998).

In order to enhance biofilm formation, fixed-film reactors may be inoculated using activated sludge from wastewater treatment plants with suspended growth process (Xie *et al.* 2004, Raj and Murthy 1998, Sharvelle *et al.* 2008) or attached biofilm from fixed-film reactors

(Green *et al.* 2006, Zhu and Chen 2002). Zhou *et al.* (2007) used purchased microorganisms created specially for enhancing municipal wastewater microbiology in fixed-film treatment systems. Biofilm may also be matured without any special inoculation, only by feeding wastewater to a reactor for some time (Mijaylova Nacheva *et al.* 2008, Orantes and Gonzalez-Martinez 2003, Ulug and Ucuncu 1992).

On the grounds of various authors, start-up of fixed-film reactors may take from 3 to 60 days (Orantes and Gonzalez-Martinez 2003, He *et al.* 2007, Yu *et al.* 2008, Green *et al.* 2006, Mijaylova Nacheva *et al.* 2008). For example, Moore *et al.* (2001) observed rapid start-up of tested biological aerated filters regarding suspended solids and chemical oxygen demand removal: the reactors reached stable removal of these substances on the third day of operation, whereas nitrification was first observed on day 20 of operation. On the other hand, Yu *et al.* (2008) reported start-up period of 7 weeks for tested biological aerated filters at 20–26 °C.

One of the reasons for various start-up durations could be the temperature of wastewater. Fdez-Polanco *et al.* (1994) found that wastewater temperature had a great impact on the performance of biofilters with up to 2 % deterioration in nitrification performance for every 1 °C change in temperature. On the other hand, Zhu and Chen

(2002) claims that the temperature has a lesser effect on nitrification performance in fixed-film processes than in suspended growth processes since fixed-film processes are influenced by phenomena which are not typical for suspended growth processes (for example, diffusion mass transport). They analysed nitrification performance of fixed-film reactors at various temperatures and discovered that the difference between the nitrification rates was not significant at 14, 20 and 27 °C, while only at the lowest temperature of 8 °C the nitrification rate was lower. This corresponds to the results of investigation performed by Payraudeau *et al.* (2000) who discovered that the effect of temperature on nitrification in floating media biofilters was visible only when the temperature was lower than 14 °C. Besides, He *et al.* (2007) and Mann *et al.* (1998) compared the impact of wastewater temperature on the removal of chemical oxygen demand and nitrification and discovered that wastewater temperature had a more significant influence on ammonium removal than on chemical oxygen demand removal.

Rock or plastic packing are the most widely used media for trickling filters (Tchobanoglous *et al.* 2003). Mondal and Warith (2008) investigated the use of shredded tires as packing medium in trickling filters for landfill leachate treatment. However, there is currently a small number of papers on using other media in trickling filters. Therefore, the objectives of this work were to investigate the start-up performance of trickling filters using a novel filter medium for suspended solids, biochemical oxygen demand and ammonium removal at low wastewater temperature and to evaluate the suitability of tested filter medium as packing medium for biofilm formation in trickling filters. Besides, the focus in this study was done on the treatment of small quantities of domestic wastewater originated from one to several households.

## 2. Materials and methods

### 2.1. Filter medium

Stonewool substrate (trademark Growcube, manufacturer Grodan, The Netherlands) for container plant cultivation was used as the trickling filter medium (Figure 1). The substrate is comprised of separate, equally sized cubes. Commercially, the substrate is offered within two different dimensions of cubes: 1x1x1 and 2x2x2 cm. The manufacturer claims that the substrate has excellent water retention properties and ensures the high percentage of air in the plant container. Besides, the increased degree of compaction applied during the manufacturing of the substrate enables the substrate to retain its shape and structure over time. Because of these substrate's properties it was assumed that the stonewool substrate for container plant cultivation could be used as an effective filter medium in a trickling filter. First of all, since the substrate ensures the high percentage of air, natural ventilation system can be used. Secondly, the recirculation of wastewater often applied in trickling filters in order to maintain the humidity of the medium can be omitted be-

cause the substrate effectively retains water. Finally, because of good water retention properties of the substrate the influent wastewater could be delivered to a trickling filter intermittently, thus a trickling filter with the stonewool substrate medium could be used for the treatment of small quantities of domestic wastewater from one to several households which is susceptible to uneven generation during a day.



**Fig 1.** The stonewool substrate: A – 1x1x1 cm cubes, B – 2x2x2 cm cubes

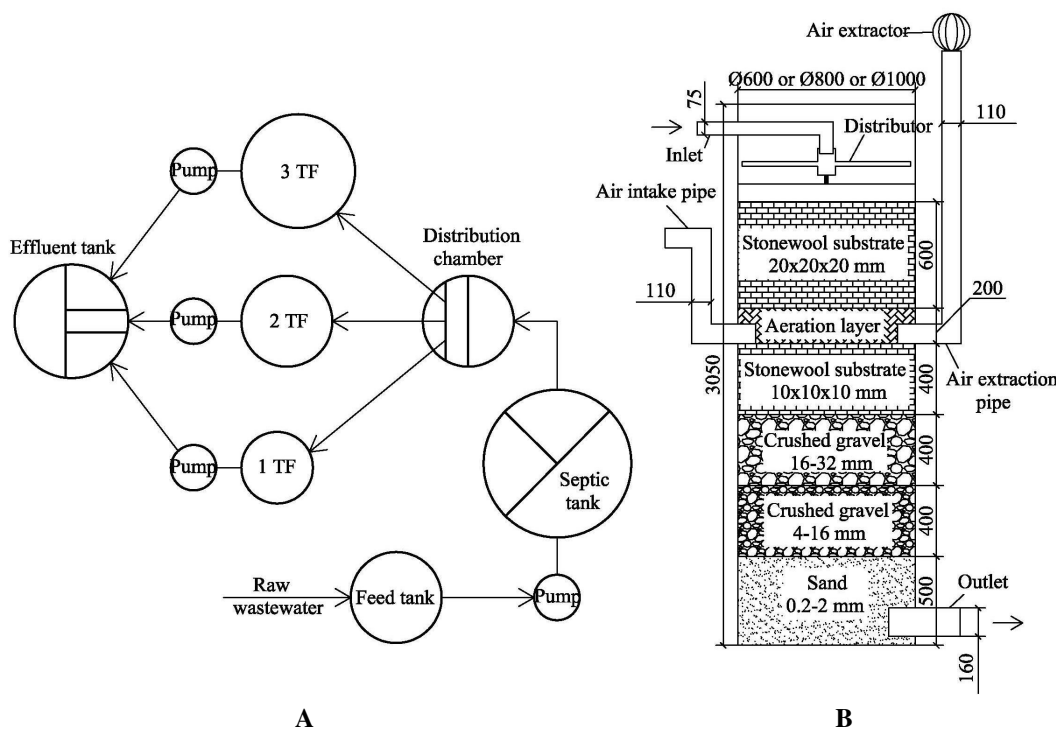
### 2.2. Experimental set-up and procedure

The pilot plant comprised of the influent wastewater feed tank, the septic tank, the distribution chamber, three polypropylene (PP) trickling filters run in parallel and the effluent tank. The system was installed outside and operated at wastewater temperature of 2.5–8.5 °C. The study has been carried out over a period of 123 days and is still continued. During first 40 days of operation, the temperature of wastewater was in the range of 7.5–8.5 °C, while after day 40 the ambient temperature dropped significantly causing a decrease of wastewater temperature to 2.5–6.0 °C. The schematic diagram of the experimental system is presented in Figure 2A.

The raw wastewater was taken from Maišiagala (Lithuania) municipal wastewater treatment plant and was collected in a feed tank. In order to avoid accumulation of solids in the feed tank, wastewater in the feed tank was constantly mixed by a mixer. In order to prevent fouling of the filters, the raw wastewater from the feed tank was pumped into the three chamber septic tank where a part of suspended solids was removed. Effluent from the septic tank flowed by gravity through the distribution chamber to the trickling filters. The purpose of the distribution chamber was to evenly distribute wastewater flow to three trickling filters.

Each filter had a cover, was cylindrical in shape with an overall height of 3.05 m and the diameter of 0.6 m (labelled as 1 TF), 0.8 m (labelled as 2 TF) and 1.0 m (labelled as 3 TF) (Figure 2B).

Treated domestic wastewater from a single household is often discharged to the soil as there is no recipient water body nearby. Infiltration wells are often used for this purpose. Therefore, the pilot scale trickling filters had two functions: the upper part of the filters comprised of the stonewool substrate worked as a biological



**Fig 2.** The schematic diagram of the experimental system (A) and the trickling filters (B)

treatment facility, while the lower part comprised of crushed gravel and sand and served as an infiltration well. The total height of the media within the filters was 2.50 m. The bottom of the filters was packed with 50 cm depth layer of washed sand with particle diameters ranging between 0.2–2 mm. Two layers of washed crushed gravel, both of 40 cm depth, were placed over the sand layer. The lower gravel layer was comprised of particles with size of 4–16 mm, while the diameter of the particles in the upper layer ranged between 16–32 mm. Finally, 100 cm depth layer of the stonewool substrate was packed above the upper gravel layer. The stonewool substrate layer comprised of two sublayers with different media dimensions. The upper sublayer was of 60 cm depth and was filled with 2x2x2 cm substrate cubes. The effluent from the first sublayer was oxidized in 20 cm depth aeration layer filled with chopped drainage pipes with a diameter of 50 mm. The lower sublayer was of 40 cm depth and was packed with 1x1x1 cm substrate cubes.

Influent wastewater was introduced at the top of each filter using manually rotated six arm distributor with drilled holes made of stainless steel. The effluent of the trickling filters was discharged from the bottom of the filters and was pumped into the effluent tank. The effluent tank was divided into three sections by means of plastic walls, thus the effluent of each filter was collected into a separate section.

The air was introduced into the filters by natural ventilation. For this purpose, the filters were equipped with air intake and extraction pipes with a diameter of 110 mm. The difference between the intake and extraction pipes' height was 2 m. In order to enhance natural ventilation, the ventilation outlets were fitted with wind-driven air extractors.

The start-up of the trickling filters was performed without any special inoculation. In order to mature the biofilm, effluent from the septic tank was fed to the trickling filters. Initially the wastewater was fed at a flowrate of 0.25 m<sup>3</sup>/d to each filter. On day 40 of operation flowrate was increased to 0.75 m<sup>3</sup>/d to each filter in order to accelerate the growth of nitrifying bacteria. Flowrate distribution over the day was selected to simulate the conditions of water use in a household according to LST EN 12566-3+A1: 2009. The daily flow pattern is presented in Table 1.

**Table 1.** Daily flow pattern in a single household

Period, h	Percentage of daily volume, %
3	30
3	15
6	0
2	40
3	15
7	0

### 2.3. Feed wastewater

The raw wastewater from Maišiagala (Lithuania) municipal wastewater treatment plant was used as the influent to the experimental system. The effluent from the septic tank was fed to the trickling filters. The quality of the raw wastewater fluctuated throughout the experimental period, therefore the quality of septic tank effluent was also unstable. The characteristics of the wastewater fed to the filters are presented in Table 2.

**Table 2.** Chemical composition of the wastewater fed to the trickling filters

Parameter	Range, mg/l	Average, mg/l
SS	75–675	215
BOD <sub>7</sub>	72–306	187
NH <sub>4</sub> -N	23.4–59.4	44.6

### 2.4. Analytical methods

In this study only the trickling filters' performance, not the overall performance of the experimental system, was analysed. Starting from the second week of filters' operation, 24-h composite influent and effluent samples of the filters were taken once a week with portable water samplers Buhler 1000 (manufacturer Hach Lange, Germany). The samples were analysed for suspended solids (SS), 7-day biochemical oxygen demand (BOD<sub>7</sub>), ammonium nitrogen (NH<sub>4</sub>-N), nitrite nitrogen (NO<sub>2</sub>-N) and nitrate nitrogen (NO<sub>3</sub>-N) concentrations. All samples were analysed according to standard methods.

### 3. Results and discussion

The trickling filters were operated for combined removal of organic matter and nitrification at wastewater temperature of 2.5–8.5 °C. During the experiment, it was observed that tested trickling filters were also capable of removing suspended solids.

On day 104 of operation the fouling of 1 TF filter was observed. The clogging of the filter could be related to the fouling of trickling filter outlet, since in order to prevent passing of sand to the effluent a bag packed with the stonewool substrate was put on the outlet of each filter. However, true reasons of fouling will be found out only after dismantling the filter. After clogging 1 TF filter did not operate as a trickling filter anymore: when wastewater was fed to the filter, water level in the filter was increasing and the medium used to become floated, whereas at hours with no wastewater supply water level in the filter was gradually decreasing. Therefore, after the clogging the performance of 1 TF filter was not analysed. However, as can be seen from Figures 5, 7 and 8, the deterioration of 1 TF filter operation was first observed at approximately day 90. Starting from this day, the removal efficiencies of BOD<sub>7</sub> and nitrification in 1 TF were gradually decreasing. It could be supposed that clogging of the filter occurred earlier and coincided with the deterioration of the filter performance. The clogging of 1 TF was not observed earlier than day 104 because due to low ambient temperatures the covers froze on to the filters, so it was impossible to open the filters. Therefore, evaluating removal efficiencies in 1 TF, only the first 90 days of operation are taken into account.

The changing trends of SS, BOD<sub>7</sub>, NH<sub>4</sub>-N and NO<sub>3</sub>-N in the influent and effluent of the filters are shown in Figures 3, 5, 7 and 8. The SS and BOD<sub>7</sub> removal efficiencies of all the filters are presented in Table 3.

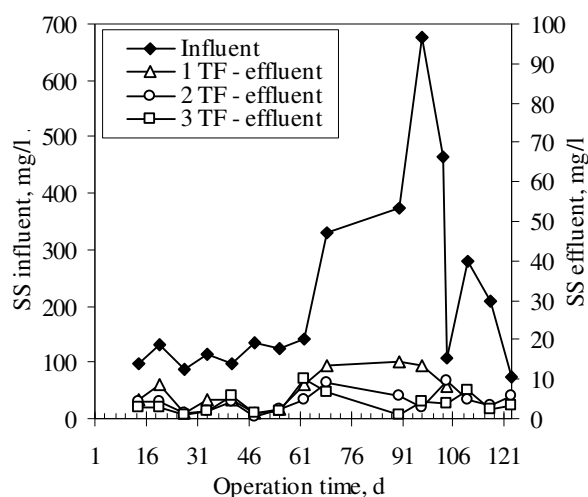
**Table 3.** SS and BOD<sub>7</sub> removal efficiencies of the trickling filters

Removal efficiency, %	1 TF	2 TF	3 TF
SS	96.1±1.9	96.9±2.4	97.5±1.9
BOD <sub>7</sub>	92.6±3.3	94.3±4.0	94.9±3.3

In order to avoid channelling and achieve maximum efficiency of a trickling filter, influent wastewater should be distributed over a medium as evenly as possible (Wik 2003). During the experiment, influent wastewater was introduced at the top of each filter using manually rotated six arm distributor with drilled holes. However, during time drilled holes in the distributors fouled with a biological slime and due to the design of the distributors it was complicated to remove the slime from the holes. Besides, it emerged that the distributors were not levelled properly. Therefore, non-uniform biofilm formation on the top of the medium was observed. However, the experiment was continued considering the fact that such a distribution system was not effective and other distribution systems should be used in real wastewater treatment facilities. On the other hand, as can be seen from Table 3, uneven distribution of wastewater did not influence the removal efficiency of tested trickling filters in regard to SS and BOD<sub>7</sub> removal and the removal of these substances remained high throughout the experiment.

#### 3.1. SS removal

During the experiment, it was observed that tested trickling filters were capable of removing suspended solids which is not typical for conventional trickling filters with rock or plastic packing. Suspended solids removal in tested filters was performed by the stonewool substrate used primarily as a biofilm carrier.



**Fig 3.** SS concentrations in the influent and effluent of the trickling filters

As can be seen from Figure 3 and Table 3, despite highly variable SS influent concentrations SS removal efficiency was higher than 90 % in all the filters and SS

concentrations in the effluent ranged between 0.6 and 14.4 mg/l. Therefore, when using the stonewool substrate as a medium in trickling filters, a sedimentation tank which is usually installed after a trickling filter could be eliminated.

As presented in Figure 4, SS removal efficiency did not depend on the volumetric SS loading to the trickling filters: SS removal efficiency of the filters was higher than 90 % when the volumetric SS loading was up to 1 kg SS/m<sup>3</sup> of stonewool medium/d.

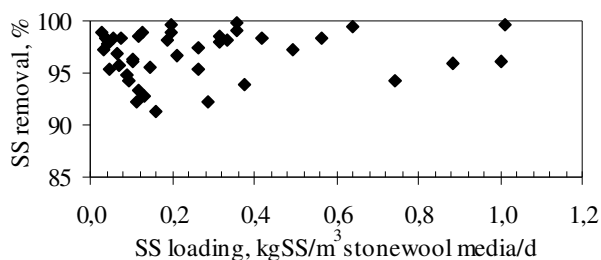


Fig 4. Effect of SS loading on SS removal efficiency

### 3.2. BOD<sub>7</sub> removal

As can be seen from Figure 5 and Table 3, BOD<sub>7</sub> removal reached steady state in two weeks of operation and was higher than 85 % in all the filters. BOD<sub>7</sub> concentration in the effluent of the filters ranged between 3.6 and 22.9 mg/l.

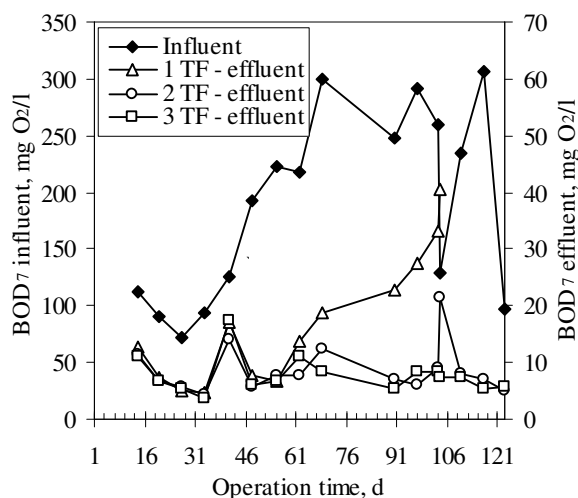


Fig 5. BOD<sub>7</sub> concentrations in the influent and effluent of the trickling filters

It can be stated that organic matter removal was associated not only with the removal of suspended BOD<sub>7</sub> fraction while removing suspended solids, but also with the biological activity of the biofilm. It was evaluated that soluble BOD<sub>7</sub> fraction in the influent to the filters comprised approximately 55 % of the total BOD<sub>7</sub> concentration, whereas after two weeks of operation BOD<sub>7</sub> removal efficiency was higher than 85 % in all the filters. Therefore, it is evident that after two weeks of operation there was enough biofilm in the filters to remove soluble fraction of BOD<sub>7</sub>.

As can be seen from Figure 6, likewise SS removal, BOD<sub>7</sub> removal efficiency also did not depend on the volumetric organic loading to the trickling filters: BOD<sub>7</sub> removal efficiency of the filters was higher than 85 % when the volumetric organic loading was up to 0.8 kg BOD<sub>7</sub>/m<sup>3</sup> of stonewool medium/d. Whereas Tchobanoglous et al. (2003) indicates that recommended organic loading for low-rate trickling filters without recirculation is 0.07–0.22 kgBOD<sub>5</sub>/m<sup>3</sup>/d (or approximately 0.08–0.25 kgBOD<sub>7</sub>/m<sup>3</sup>/d). Under this loading a trickling filter can reach 80–90 % efficiency of organic matter removal, while increasing the loading reduces BOD removal efficiency.

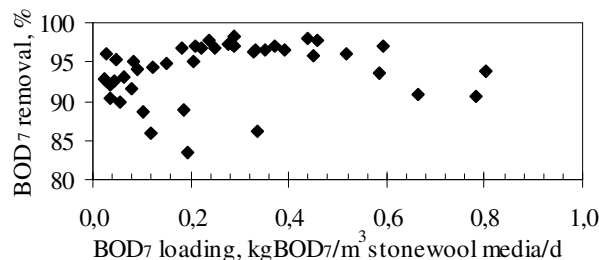


Fig 6. Effect of organic loading on BOD<sub>7</sub> removal efficiency

### 3.3. Nitrification performance

As presented in Figures 7 and 8, nitrification occurred only on day 90 of operation. Starting from this day, nitrate nitrogen concentrations in 2 TF and 3 TF filters effluent started to increase. However, nitrification efficiency of these filters was not high throughout the experimental period and the highest value of 40.9 % was reached on day 117 of operation in 2 TF trickling filter. Such a long set-up period for nitrification could be related to the low wastewater temperature as nitrifying bacteria are sensitive to low temperature. Nevertheless, the authors expect the further increase in nitrification as the experiment is still continued.

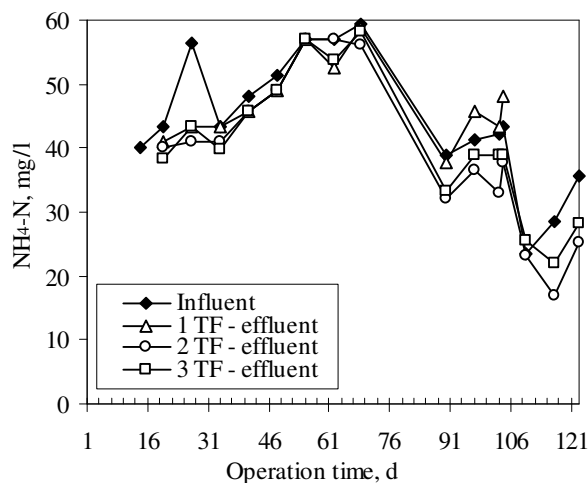
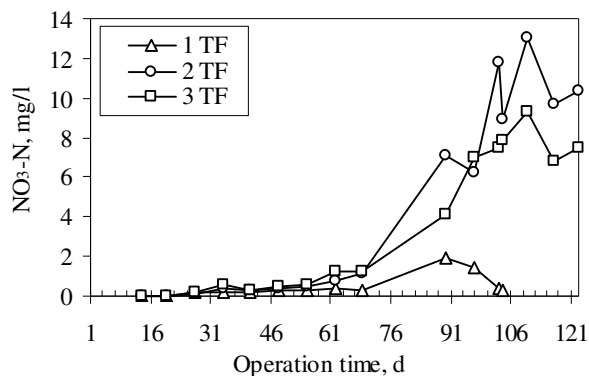


Fig 7. NH<sub>4</sub>-N concentrations in the influent and effluent of the trickling filters



**Fig 8.** NO<sub>3</sub>-N concentrations in the effluent of the trickling filters

Throughout the experimental period nitrite nitrogen concentrations in the effluent of all the filters did not exceed 1 mg/l (except on day 34 when nitrite nitrogen in 3 TF effluent reached 2.6 mg/l).

#### 4. Conclusions

1. Low temperature did not have an impact on the removal of SS and BOD<sub>7</sub>: the removal of these substances reached steady state in two weeks of operation, the efficiency of SS removal was higher than 90 %, while removal efficiency of BOD<sub>7</sub> was higher than 85 % in all the filters.
2. SS removal efficiency of the trickling filters did not depend on the SS volumetric loading to the filters up to 1 kg SS/m<sup>3</sup> of stonewool medium/d and BOD<sub>7</sub> removal efficiency of the filters also did not depend on the volumetric organic loading up to 0.8 kg BOD<sub>7</sub>/m<sup>3</sup> of stonewool medium/d.
3. Nitrification occurred only on day 90 of operation and it was not high throughout the experimental period (the highest value of 40.9 % was reached on day 117 in 2 TF filter). Such a long set-up period could be related to the low wastewater temperature (2.5–8.5 °C) and further increase in nitrification is expected as the experiment is still continued.
4. The stonewool substrate can be used in trickling filters as a biofilm carrier since trickling filters with this substrate successfully removed BOD<sub>7</sub> from wastewater. Besides, using the stonewool substrate as a medium in trickling filters, a sedimentation tank which is usually installed after a trickling filter could be eliminated as the stonewool substrate successfully removes SS from wastewater.

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