End of Life Tyre (ELT) Rubber Material as Biofilter Carrier

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Abstract

The study examined the use of rubber shreds made of end of life tyres (ELT) as the carrier in biofilters used in waste water treatment. When tyres are taken off vehicles, they become part-worn tyres or end of life tyres, ELTs**.** ELTs that are mechanically sheared into shreds ranging in size from 25–300 mm and intended for use in civil engineering applications are called *Tyre Derived Aggregate (TDA)***.**

The project was ordered and funded by Finnish Tyre Recycling Ldt. and Kuusakoski Ltd. and the study was carried out at the City of Heinola's municipal waste water treatment plant from August 2012 till October 2013. The research equipment consisted of a transportable container which contained three independently operating bioreactor units filled with TDA materials. TDA materials with three different particle sizes were used as carriers in reactors: 15 mm x 15 mm in filter **1**, 50 mm x 50 mm in filter **2** and 100 mm x 300 mm in filter **3**. Water was led to these units from the water treatment plant's secondary settling reservoir at the rate of approximately 300 litres per hour per filter.

After the microbe activity had initiated, based on the results, all three filters succeeded in reducing the total nitrogen and ammonium nitrogen content moderately (30–40 %), and at times, significantly, by more than 70 %. The total phosphorus was reduced by approximately 40 %. At best, the phosphorus removal from the water was excellent, up to 80 %. Also, the BOD and COD loads were slightly reduced. Comparing the TDA materials of different sizes, the best purification results were achieved with the largest particle size, 100 mm x 300 mm.

The rubber biofilter’s ability to retain significant amounts of phosphorus from the waste water was a particularly interesting result. This may be due to the iron contained in the shredded tyre material; it has the ability to precipitate the phosphorus from its soluble form. Further research needs to be carried out on this characteristic of the TDA material and the continuity of the effect.

Based on the study it can be perceived that TDA material can act as a carrier in a biofilter, and it contributes to removing nutrient content from waste water. However, the operation of the biofilter is sensitive to changes and malfunctions in the operation of the waste water processing plant. Microbe activity is easily disturbed due to changes in conditions such as temperature and flow rate. The operational reliability of the equipment must be improved and tested when developing commercial applications.

1. Introduction

When tyres are taken off vehicles, they become part-worn tyres or end of life tyres, ELTs**.** ELTs that are mechanically sheared into shreds ranging in size from 25–300 mm and intended for use in civil engineering applications are called *Tyre Derived Aggregate (TDA)***.**

The filtering characteristics of shreds and granulates made of ELTs in municipal waste water treatment have been extensively studied. For example in some states in the America its use is approved in private household waste water treatment applications. Studies show that biofilter using shredded tyre purifies efficiently solids, organic matter, nitrogen and phosphorus from waste water. As already demonstrated by the existing ways to utilize shredded tyre materials in road and earth construction and landfill structures, fresh raw materials can be safely replaced by tyre materials.

According to the experience from waste water treatment and research data, the TDA can act as a growth media for biofilm, which efficiently purifies nutrients from the waste water. In addition, the iron (Fe) contained in the tyre material may precipitate phosphorus (P) from the waste water. In Finland, TDA is an environmentally approved construction material in earth construction and landfill structures. No harmful substances have been found to dissolve from TDA in water or soil, even in applications related to waste water treatment.

1.2 Aims of the research

The purpose of the study was to examine the applicability and efficacy of shredded ELT material, TDA for purification of waste water in industrial biofilter applications in facilities where considerable quantities of water are generated and purified.

2. Experimental

The test equipment used in the research was constructed in a transportable container (Figs. 1 and 2). The equipment had three reactors filled with shredded ELT material, TDA, and operating independently of each other. The particle sizes of the TDAs used in the different reactors were:

- Filter **1** 15 x 15 mm
- Filter **2** 50 x 50 mm
- Filter **3** 100 x 300 mm

In the winter, the temperature of the water flow to the filter was approximately 4–5 ^{o}C and in the summer, approximately 15 ^{o}C. The electrification and automation were carried out using a logics-based system (Fig. 3a). The water piping had valves for sampling (Fig. 3b).

The water to be filtered was led into each reactor separately at the top and the filtered water ran out at the lower part of the reactor. The filter media was cleaned with backwashing twice a day. The water to be treated was taken from the secondary treatment reservoir of the City of Heinola waste water treatment plant and it was returned into the pre-treatment reservoir.

The filter bed was aerated through the lower part of the filter reactor. The process was controlled with an electric automation system. The functions necessary for the operation were connected to an alarm function. The volumetric flow rate into each reactor was approximately 300 litres per day. The biofilters were allowed to start cold.

Sampling (Fig. 3b) was carried out simultaneously with the sampling consistent with the environmental permit terms of the waste water treatment plant so that the results would be as comparable as possible. The total monitoring and sampling period was divided to three phases due to outages in water flow due to maintenance operations in plant.

Phase 1 (August 2012). The sampling begun on 28th August 2012. First three samples were taken daily. The second four samples were taken once a week. After that, sampling was done every two weeks.

Phase 2 (January 2013) and 3 (August 2013). The first sample was taken a week after the start-up. After this, four samples were taken once a week and then once every two weeks.

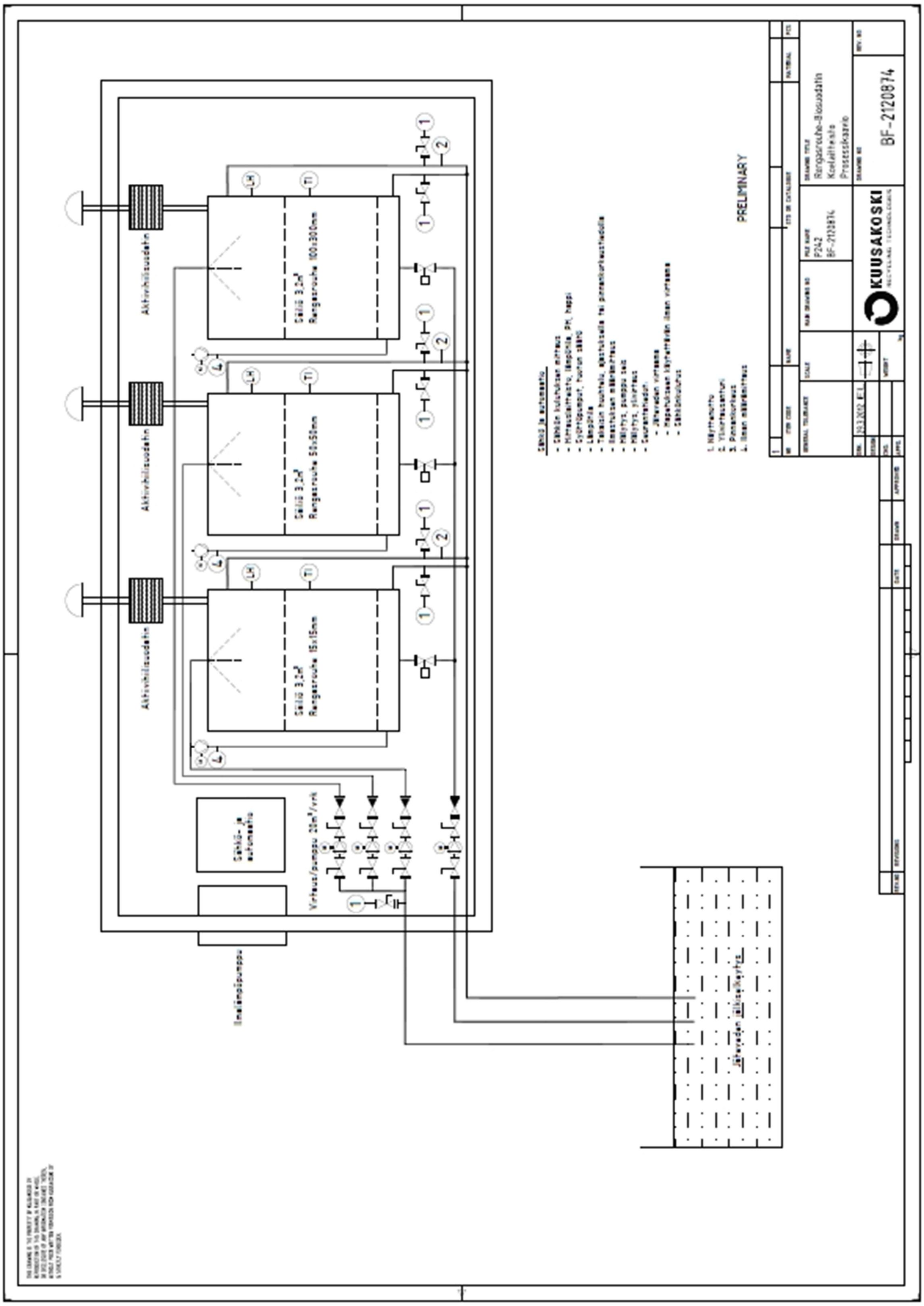


Figure 1. Diagram of the filter container.

Figure 2. a) The filter container from outside and b) filters inside the container.

Figure 3. a) Control panel of the filter system and b) sampling**.**

The following variables were examined in the research:

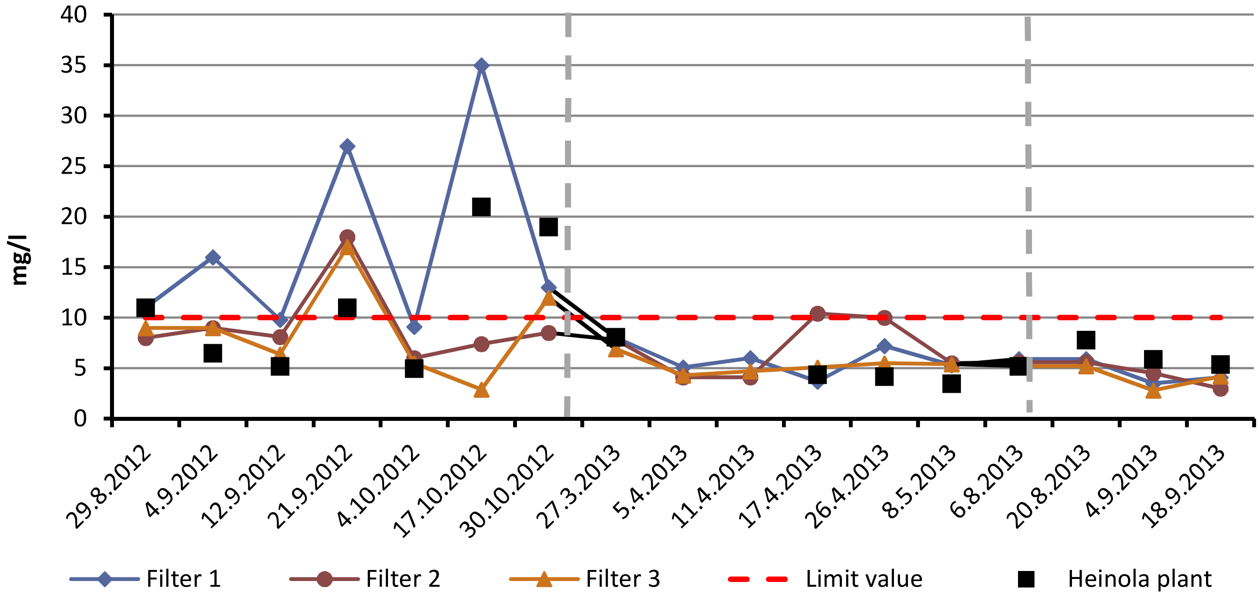
- BOD_7 Biological Oxygen Demand (BHK_7) and COD Chemical oxygen demand
- N_{TOT} Total nitrogen content and ammonium nitrogen
- P_{TOT} Total phosphorus
- Oxygen, pH and alkalinity
- Solid matter, conductivity

3. Results

3.1 Biological oxygen demand (BOD_7)

At the initiation stage of the biofilter (phase 1), it was detected that the water's biological oxygen demand BOD_7 (Graph 1) varied considerably in both the ingoing and filtered water. However, in October 2013, continuous purifying effect of filters **2** and **3** could already be detected in the BOD_7 result. During the phase 2, the BOD_7 behaviour was already much more uniform (spring 2013), and during the phase 3, (autumn 2013), the BOD_7 became stable quickly and at this stage, clearer purification results were achieved with all filters, while the reduction was approximately 25 %.

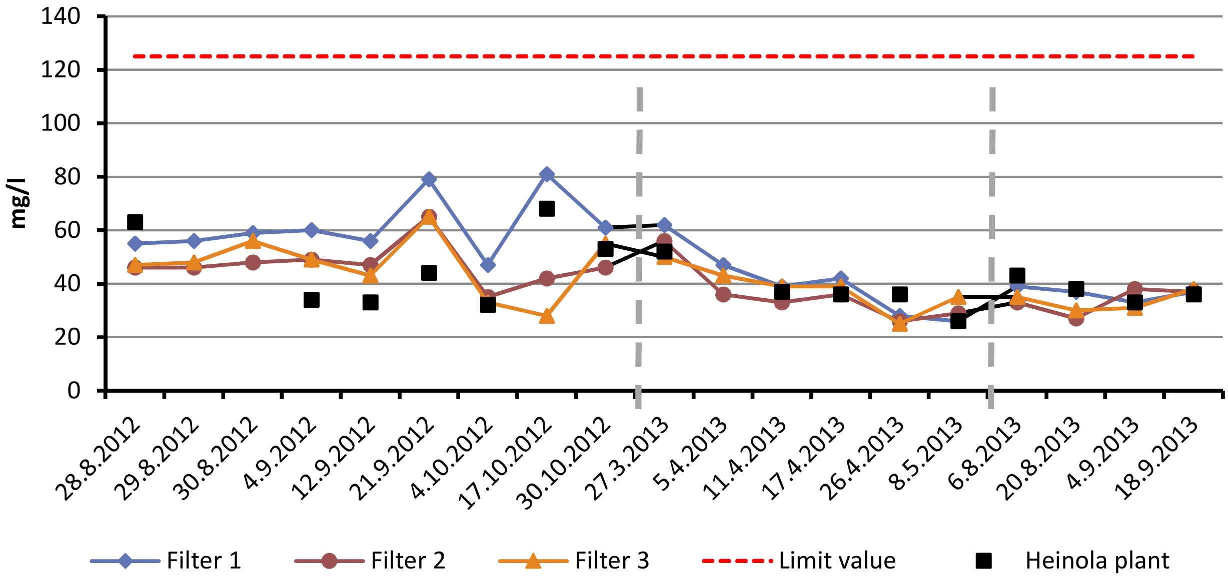
Graph 1. BOD_7 in filters **1**, **2** and **3** compared with the secondary settling output water at the Heinola waste water treatment plant. The vertical lines describe phases 1 – 3, due to maintenance.



3.2 Chemical oxygen demand (COD)

Results could be detected quickly in terms of chemical oxygen demand. Approximately a month from start-up, a purification result of nearly 60 % was achieved with filter **3** and approximately 40 % with filter **2**. In filter **1**, the COD values remained high. Equivalent results were also achieved later during the monitoring.

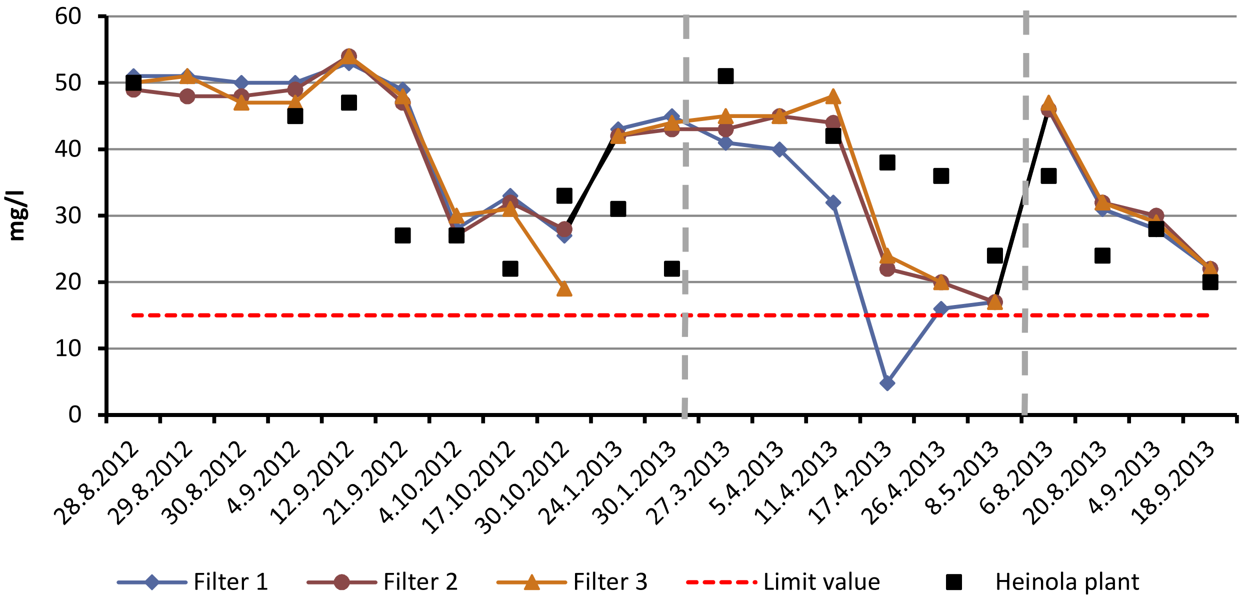
Graph 2. COD in filters **1**, **2** and **3** compared with the secondary settling output water at the Heinola waste water treatment plant. The vertical lines describe phases 1 – 3, due to maintenance.



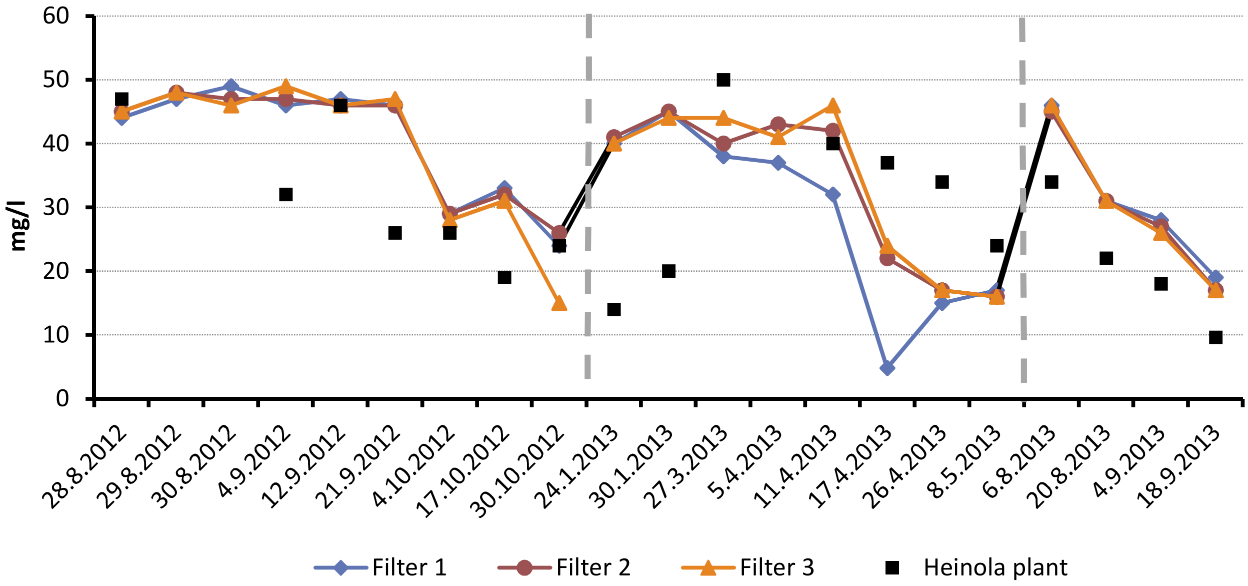
3.3 Total nitrogen (Tot-N) and ammonium nitrogen (NH_4-N)

Nitrogen removal began in filter **3** after the filter had been operational for approximately two months (phase 1). During the second phase, when the biofilter system had been operating continuously for 36 days, the retention capabilities of the filters were **1**: 89 %, **2**: 40 % and **3**: 37 %. After this, the differences between the filters evened out. During phase 1, removal of ammonium nitrogen (Graph 4) was detected in two months, reduction of ammonium nitrogen being 38 % in filter **1**. During the phase 2, the microbe activity initiated quicker and the purification results were detected already a month from the restart of the reactor.

Graph 3. Total nitrogen in filters **1**, **2** and **3** compared with the secondary settling output water at the Heinola waste water treatment plant. The vertical lines describe phases 1 – 3, due to maintenance.



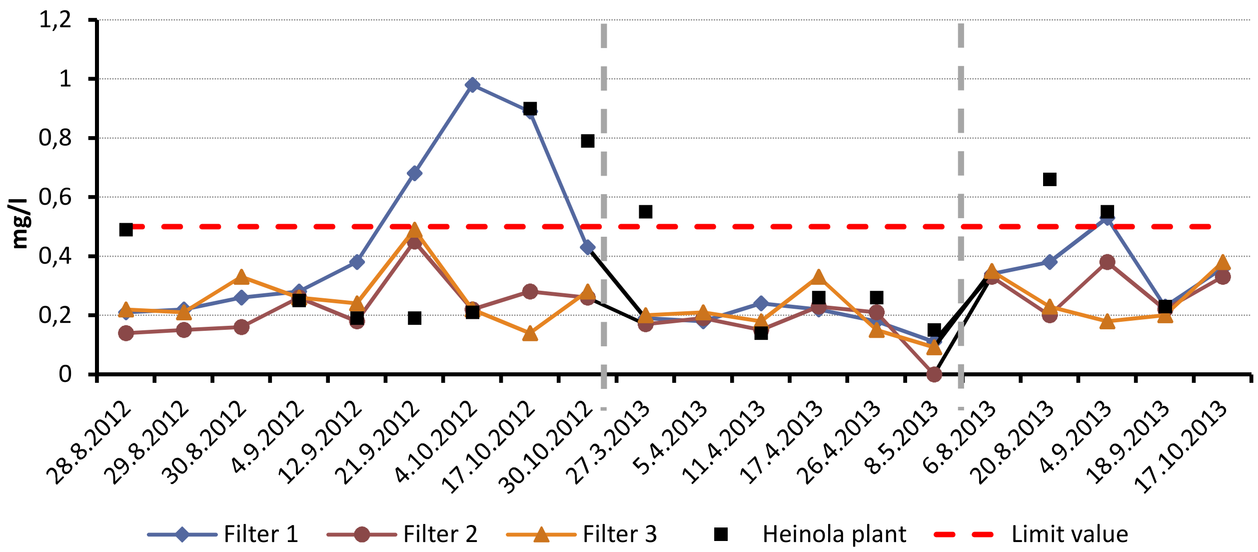
Graph 4. Ammonium nitrogen in filters **1**, **2** and **3** compared with the secondary settling output water at the Heinola waste water treatment plant. The vertical lines describe phases 1 – 3, due to maintenance.



3.4 Total phosphorus (tot-P)

All biofilters seemed to retain total phosphorus right after their start-up. Total phosphorus removal functioned best in filter **2**, which removed 39 % of the phosphorus throughout the research period. The reduction of filter **3** was 37 % and of filter **1** 16 %. The peak result was achieved in phase 2, after two months with filter **3**, where phosphorus reduction was as much as 85 %.

Graph 5. Total phosphorus in filters **1**, **2** and **3** compared with the secondary settling output water at the Heinola waste water treatment plant. The vertical lines describe phases 1 – 3, due to maintenance.



3.5 Solid matter

Throughout the research period, filter **3** retained 30 % of the solid matter, but the impact of filter **2** on the solid mater was marginal, having a reduction of 10 %. The solid matter content of the water having passed through filter **1** was generally higher than in the incoming water. Graph 6 on page 8.

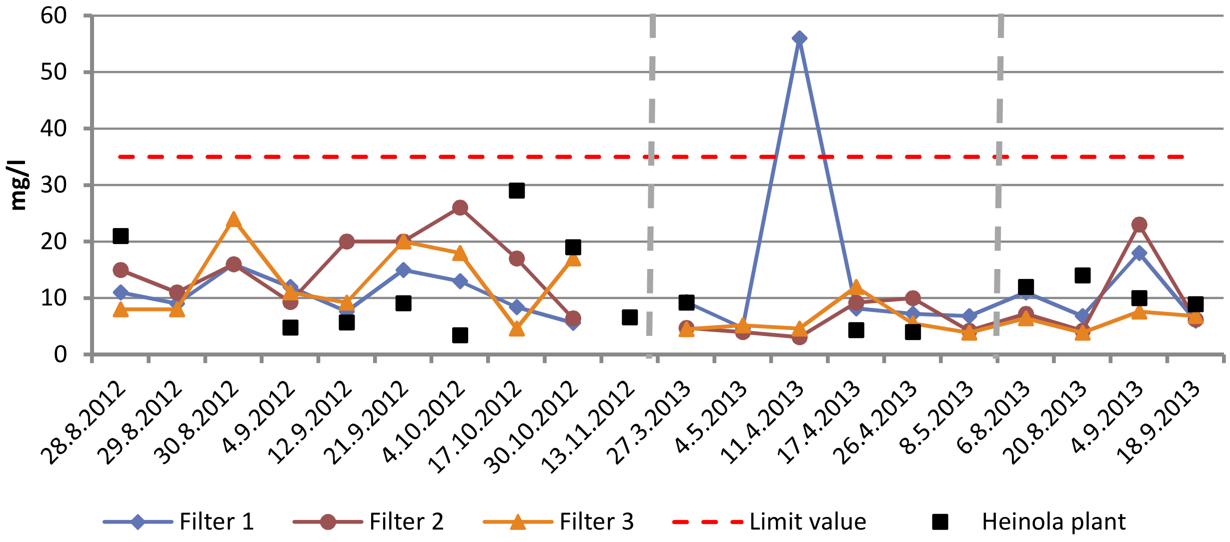
3.6 pH, alkalinity and oxygen

The pH values remained stable in all three biofilters throughout the research period. The lowest pH values (7.1-7.2) were observed in each phase after the beginning of nitrogen removal.

The first alkalinity analyses of the water filtered with TDA material were performed in phase 2, January 2013. Based on the results, alkalinity was low when the biofilters functioned correctly.

Oxygen was fed into the filters throughout the research period using an aerating pump. Aeration was increased considerably toward the end of the research. In all the filters, the best removal results for nitrogen, for example, were achieved when the oxygen level was about 10mg/l.

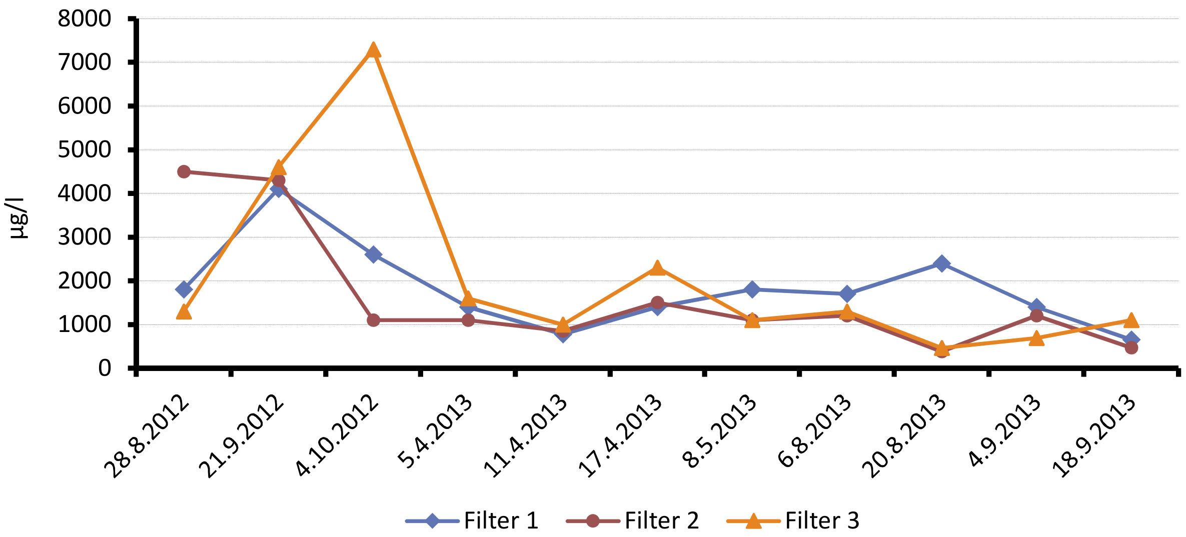
Graph 6. Solid matter in filters **1**, **2** and **3** compared with the secondary settling output water at the Heinola waste water treatment plant. The vertical lines describe phases 1 – 3, due to maintenance.



3.7 Metals

Chromium (Cr), copper (Cu), lead (Pb), manganese (Mn), iron (Fe) and zinc (Zn) were analysed in the output water of all the filters. No changes were detected and later, only the water's iron content was monitored. During the research (Graph 7), the most amount of iron leached from filter number **3** (22,8 mg/l). The least amount of iron leached from filter number **2** (17,7 mg/l).

Graph 7. Iron contents in the water after filters **1**, **2** and **3** during monitoring.



4. Conclusions

The initiation of the operation and the efficiency of the tyre derived aggregate (TDA) filled biofilter were assessed based on the results of waste water analyses. In phase 1, the initiation of the biofilter was concluded to have lasted approximately 2 months. During phase 2, the initiation was quicker, microbial activity starting within a month of start-up.

Based on the figures obtained at the first stage of testing, all three TDA filled biofilters reduced the quantity of total nitrogen. At this stage, filter **3** was the most efficient at reducing the quantity of total nitrogen, with a reduction of 40 %. Furthermore, it was the only filter which, according to analyses, reduced also the content of ammonium nitrogen in the water, by approximately 37 %. At the second phase of monitoring, backwashing of the TDA filter media and boosted aeration were also used. Nitrogen removal functioned well in all three filters. During a month of uninterrupted monitoring, the total reduction of nitrogen was 38—47 % and of ammonium nitrogen 44—66 %. The optimal conditions must be maintained in the biofilter bed in order to implement successful nitrogen removal.

The phosphorus retention capacity of the TDA material can be significant: the peak result, 85 % reduction, was achieved with filter **3** in phase 2, two months after start-up. However, the results indicate that the phosphorus removal occurs due to precipitation effect caused by chemical reaction with iron. The phosphorus removal functions best with larger particle sizes: with filters **2** (50x50mm) and **3** (100x300mm) a 33 % better purification result was achieved regarding phosphorus than with filter **1**. Filters **2** and **3** with larger TDA particles were also more efficient in recovering the solid matter. Due to the variation in the solid matter content, the biofilter may require secondary settling.

Based on the study it can be perceived that TDA material acts as a filterbed media in a biofilter, and it contributes to removing nutrient content from waste water. However, the operation of the biofilter is sensitive to changes and malfunctions in the operation of the waste water processing plant. The microbial activity is easily disturbed due to changes in conditions such as temperature and flow rate of water. The operational reliability of the equipment must be improved and tested when developing commercial applications.

5. Acknowledgements

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