EFFECTIVENESS OF VERTICAL REED BED FILTER FOR THE REMOVAL OF PHOSPHORUS FROM THE SURFACE WATER

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The removal of phosphorus and nitrogen is very important for the improvement of water environment. This paper describes the possible removal of phosphorus from the surface water by vertical reed bed filter with particular to the residential area of "Leidsche Rijn" of Utrecht Municipality, Netherlands. The Leidsche Rijn pilot plant consists of vertical flow reed beds with a surface area of 5000 m^2. It includes 13 filters with different filter bed mixtures running under different process conditions. In general, the removal efficiency was almost 80-90% for all the filters except the filter 4d that had not added rusting shaving iron and the performance of the filters was almost the same. The experimental results showed that sand layer with iron and calcium carbonate as an absorbent will be effective in the vertical reed bed filter for the removal of phosphorous from the surface water.

Key Words: *Adsorption, phosphorous, reed beds, vertical flow system, removal efficiency*

1. INTRODUCTION

The “Leidschse Rijn” area was historically considered as an agriculture area and therefore the phosphate levels were considered to be rather high. Phosphate is a major nutrient for algae and the amount of algae should be minimized. Nitrogen is also a nutrient that stimulates the growth of algae, but, in the Leidsche Rijn area phosphate is the key element. Therefore, the removal of phosphorus is very important measure for the improvement of water environment in the Leidschse Rijn. Here, a vertical reed bed filter was treated as the phosphate removal technique. The main purpose of the reed bed filter is to achieve optimum water quality by removing phosphate from the surface water. It is a leading example of technological advances in sustainable urban drainage.

The aim of the study is to create a sustainable water system of the Leidsche Rijn for enabling recreational activities like: swimming, fishing and canoeing. Therefore intensively data analysis has been done for the reed bed filters. The Leidsche Rijn surface water system will incorporate a reed and filter bed to ensure a good water quality level. The reed and filter beds will be used to polish the circulating water within the system. In this paper, the practicability of using iron as an adsorbent for phosphorous removal in the surface water has been analyzed. The adsorption capacity of the iron will be determined under intermittent aerobic conditions and the effect of other compounds e.g. calcium carbonate, on the adsorption process will be studied using the data of the full-scale experimental pilot plant at Leidsche Rijn.

From this study, it could be anticipated that sand layer with iron and calcium carbonate as an absorbent will be effective in the removal of phosphorus in the surface water. Moreover, it is expected that effluent water quality will be of the standard that can be acceptable in the natural water courses. Therefore, this removal system is environmental friendly manner.

2. LABORATORY EXPERIMENT FOR THE CASE STUDY IN "LEIDSCHE RIJN"

(1) Study area

Leidsche Rijn is the largest vinex location under construction in the Netherlands. The population projection by the year 2015 is estimated to be 90,000 people with 30,000 new housing estates. The full-scale pilot vertical reed bed filter plant is situated in the new urban area of “Leidsche Rijn” as shown in **Fig. 1**.

(2) Laboratory experiment

The laboratory experiments consisted of batch adsorption experiments and column experiments. The batch experiments were used to evaluate the performance of the blast furnace slag; granulated blast furnace slag; LD-steel slag; iron shavings and two carboneous materials i.e. calcium carbonate and dolomite. The results of these batch experiments should give a good idea of the performance of the respective adsorbents in a constructed wet land[1)].

Based on these equilibrium experiments and environmental considerations, several mixtures of calcium carbonate (limestone), sand and iron shavings were prepared for the column experiments. Two series of five-column phosphate adsorption experiments were carried out. In the first series, it was tried to approximate the actual conditions in a constructed wetland with respect to filter height (approximately 80 cm), liquid load (0.4 $m^3/m^2/day$) and influent composition. In the second series, it was attempted to determine the maximum load rate of the filter medium.

Therefore the combination of column length (approximately 160 mm), liquid load (2 $m^3/m^2/day$) and influent phosphate concentration (approximately 1.5 mg P/l) was chosen to match the phosphate load of the vertical reed bed filter during 30 years (the expected time the wetland will be in operation). The results of these (dynamic) column experiments, in conjunction with the results of the equilibrium experiments, were used to determine the performance of adsorbents in a constructed wetland.

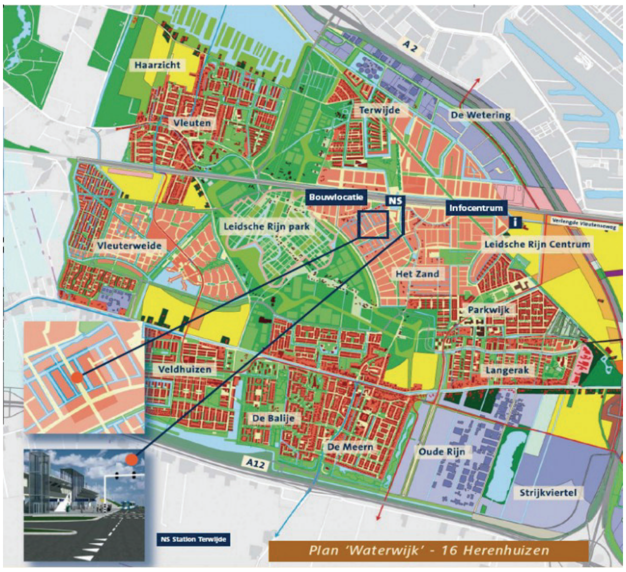


Fig. 1 Leidsche Rijn site plan (source Utrecht Council, 2005)

(3) Layout of filter

A pilot plant was designed and constructed based on the theoretical study and the laboratory experiments as shown in **Fig. 2**.

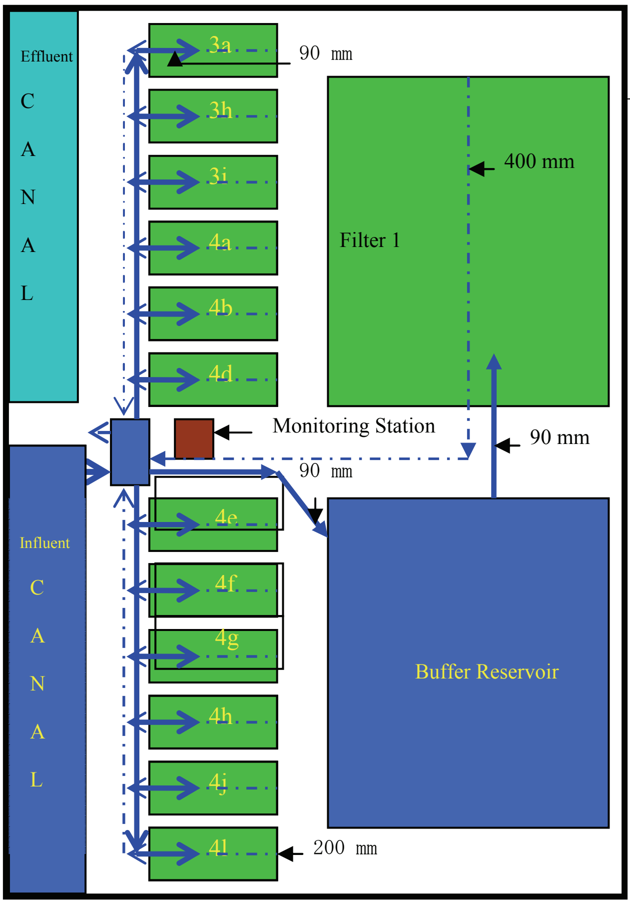
A layout of the vertical reed bed filter treatment system is shown in the **Fig. 2(a).** This system consists of twelve small filters (170m2 each), one big filter (2247m^2) with a buffer reservoir, pumps having a capacity of 40 m^3/h for all the filter, monitoring station, that regulates the inflow and outflow and operational control room where grab sample and in-situ measurements are taken.

Different composition of the materials of the pilot plant in weight percentages can be seen in **Table 1**. PF-3h acts as a reference filter, the big filter (PF-1) should acts a full scale filter, and PF-3a has a gutter-water supply system. The beds have varying media composition; iron shavings as an adsorptive media (0.0%-5.0%), fine sand to provide good filtration (87.8%-97.5%) and calcium carbonate to regulate the pH (0.0%-10.0%). Every filter had one parameter different from the other.

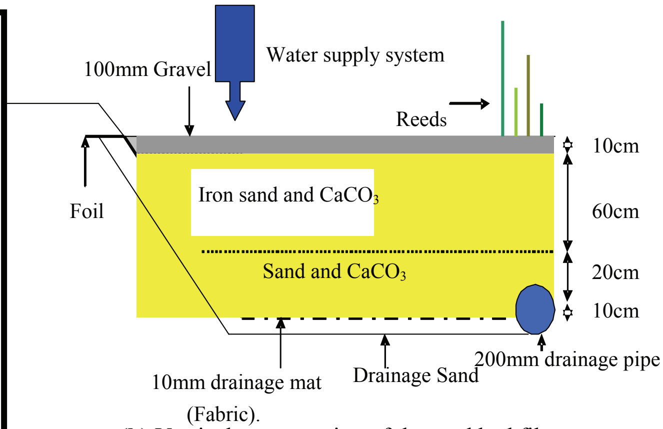
(4) Adsorbent composition

This study examines the effectiveness of the media composition and the possible role of each filter. It took approximately 7 months to construct the plant. The filters are 90 cm deep. The surface load of most sections is 0.10-0.15 $m^3/m^2/day$.

An upper layer of 10 to 15 cm shown in **Fig. 2(b)** is filled with coarse gravel. The gravels are useful for obtaining uniform water distribution. A middle layer of 60 cm is filled with a mixture of sand, calcium carbonate and iron shavings. In this layer the adsorption of ortho-phosphate must take



(a) Layout of the filter



(b) Vertical cross-section of the reed bed filter.

(c) Sampling device for grab samples (left) and in-situ parameters (right).

Fig.2 Outline of the laboratory experiments

place. A lower layer of 20 cm containing a mixture of sand and calcium carbonate is useful to prevent the iron washing out from the upper layer. The function of drainage layer has to drain the filters which should provide unhindered effluent water discharge. This has a water level of 10cm permanent to avoid bacterial growth on the fabric. An impervious geotechnical foil material that prevents contact between water in the filter and groundwater.

The first 6 filters, according to **Table 1** (PF 1 to PF 4b) have the same composition. These filters are being used to investigate the effect of process conditions such as water distribution, the surface load, and the residence time. All the filter sections, except PF 3a, are operated according to a fill and draw regime. The filters are intermittently loaded with surface water. The water is distributed over the surface of the filters in a short time (30 minutes per day) with a high flow rate. This ensures an optimum distribution of water across the reed bed surface. After percolation through the bed medium, the water is collected in the drainage pipe at the bottom of the bed. The water is being kept in every filter section

Table1 Composition of the materials of the pilot plant in weight percentages

Filter	Upper layer			Lower layer		Variations of parameters per section
	Sand	Iron shaving	Calcium carbonate	Sand	Calcium carbonate	
PF 1	92.4%	2.4%	5.2%	95.0%	5.0%	Full scale
PF 3a	92.4%	2.4%	5.2%	95.0%	5.0%	Filling system with gutters
PF 3h	92.4%	2.4%	5.2%	95.0%	5.0%	Reference filter for small filters
PF 3i	92.4%	2.4%	5.2%	95.0%	5.0%	Contact time variation
PF 4a	92.4%	2.4%	5.2%	95.0%	5.0%	Surface load 0.075 m3/m2.d
PF 4b	92.4%	2.4%	5.2%	95.0%	5.0%	Surface load 0.45 m3/m2.d
PF 4d	95.0%	0.0%	5.0%	95.0%	5.0%	No iron shavings
PF 4e	93.9%	1.2%	5.0%	95.0%	5.0%	No reed and less iron shaving
PF 4f	93.8%	1.3%	5.0%	95.0%	5.0%	Less iron shaving
PF 4g	90.2%	4.9%	4.9%	95.0%	5.0%	More iron shaving
PF 4h	97.6%	2.4%	0.0%	100.0%	0.0%	No calcium carbonate
PF 4j	87.9%	2.4%	9.7%	90.2%	9.8%	More calcium carbonate
PF 4l	92.5%	2.5%	5.0%	95.0%	5.0%	Local sand

for an hour and is then discharged. This mode of operation was selected to provide good water distribution and to maintain oxidizing conditions in the reed bed. The oxidizing conditions are necessary to produce iron oxides from the iron shavings. Only iron (hydr) oxide can adsorb ortho-phosphate.

(5) Analysis methodology

The data obtained from the full scale experiment plant was divided into laboratory, in situ and set process data analysis. This analysis considers data of approximately twenty months, falls in the periods between May 2005 to March 2007. The test site was commissioned in May 2005 and from that date on wards experiments were executed and results were collected. The filters receive surface water via a supply canal around residential houses of the new area "Leidsche Rijn". Water originates mainly from upcoming ground water and rainwater (run-off).The effluent of the treatment plant is discharged in the down stream part of the supply canal.

In Laboratory, all tests were carried out in accordance with standard for examination of surface water and wastewater. Spreadsheets were developed to analyze the grab samples. These samples were analyzed in the laboratory, as shown in **Fig. 2(c)** for phosphate and iron concentration. The in-situ water quality parameters, data were collected per minute over a specific run/campaign from the device as shown in **Fig. 2(c)**. The data was averaged to on a weekly basis to study the overall process conditions/environmental factors, affecting the filters.

3. RESULTS AND DISCUSSIONS

Data analyses were carried under different composition of bed filter media and parameters to examine the adsorption capacity of phosphorus in the vertical reed bed filters by the use of data bank in excel sheet.

(1) Surface loading rate

The designed surface loading rate for the filters was 0.15 m^3/m^2/day except for filter 4b and filter 4a. The filter 4b runs three times a day having surface loading rate 0.45 m^3/m^2/day and filter 4a have 0.075 m^3/m^2/day, refer to **Fig. 3**. All filters stopped working in between the period of Jan-March 2006. After the perfection of the adequate valves, performances of the filters are good and also they work well. In May 2006, there was a problem occurred in filter 4b that might have been due to the high surface load or again problem with valves. Then the filter was clogged. A clay layer was seen in the top of the filter. The clay layer was removed and SLR was reduced from 0.45 to 0.15 m^3/m^2/day. Afterwards the filter has been working well and the clogging problems were disappeared. About the clogging of the filter, it has not been cleared that how it appeared. It might be due to the suspended solids in the influent or might be due to the interaction among the chemical parameters.

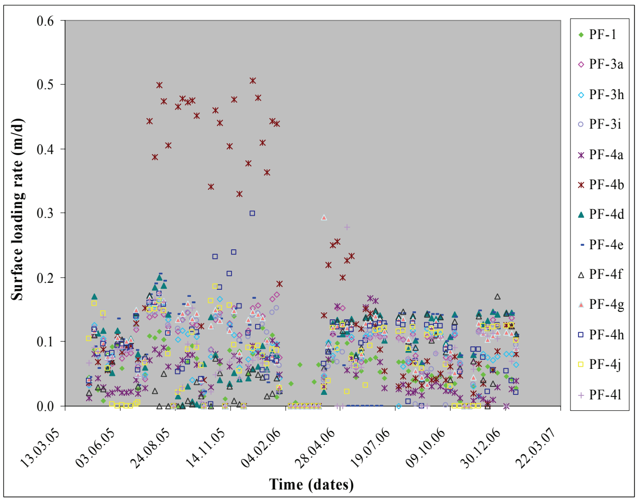


Fig. 3 Surface loading rate over the period of time

Table2 Published relationship between filtered and total phosphorous

Source	TP*/TP
McCary(2001)[4]	0.82
Tanner(1998)[6]	0.80

(2) Relation between influent and effluent phosphorus

The ratio of accumulation of phosphorus (TP*) and total phosphorus in the effluent (TP) is shown in **Table 3** which is the average of four sampling dates and compared with literature value in **Table 2**.

From **Table 3** and **Fig. 4**, it is found that the process of total phosphorus accumulations in all filters was very effective. This justifies the objective of using fine sand for filtration purposes. It is also noted that the phosphorus ratio of TP*/TP is high i.e. 0.78 and the validity is shown with comparison to the published values in **Table 2**. This ratio indicates that the TP can predominantly be removed by adsorption and a small percentage can be removed by filtration. Therefore the main removal mechanism is mainly dependant on the adsorption to the media. This establishes due to the interaction between phosphorus species and the filter material.

The overall mass balance calculations are done according to "Mass balance equations" i.e.

$$TP_{\text{influent}} = TP_{\text{effluent}} + TP_{\text{accumulation}}$$

From this overall mass balance of **Fig. 5**, it can be clearly seen that about 82% of the phosphorus can be adsorbed by iron containing adsorbent mixtures.

(3) P removal in the buffer reservoir

Table3 Relation between TP and TP*

Relation between TP,TP*				
Parameters	TP-Influent (mg/l)	TP Effluent (mg/l)	TPaccu(TP*) (mg/l)	TP*/TP
INF	0.208			
PF-BUF	0.208	0.130	0.078	0.374
PF-1	0.208	0.033	0.175	0.843
PF-3a	0.208	0.033	0.175	0.842
PF-3h	0.208	0.030	0.177	0.854
PF-3i	0.208	0.055	0.152	0.733
PF-4a	0.208	0.028	0.180	0.867
PF-4b	0.208	0.029	0.179	0.863
PF-4d	0.208	0.086	0.122	0.587
PF-4e	0.208	0.037	0.171	0.823
PF-4f	0.208	0.025	0.182	0.879
PF-4g	0.208	0.028	0.180	0.866
PF-4h	0.208	0.051	0.157	0.756
PF-4j	0.208	0.045	0.163	0.785
PF-4l	0.208	0.038	0.170	0.819
Average	0.208	0.046	0.162	0.778

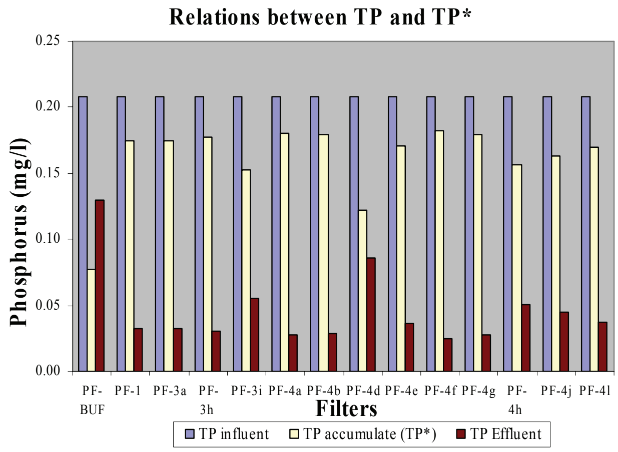


Fig. 4 The relationship between TP and TP*

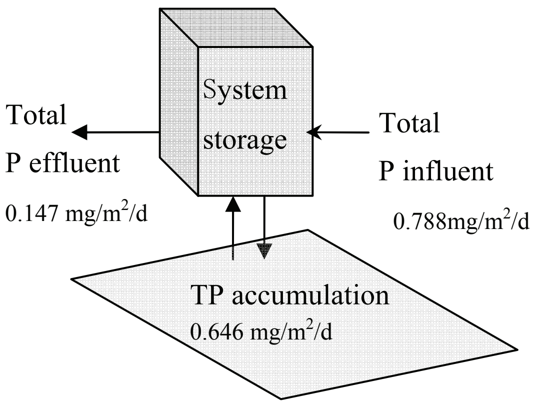


Fig.5 Mass balance of total phosphorus

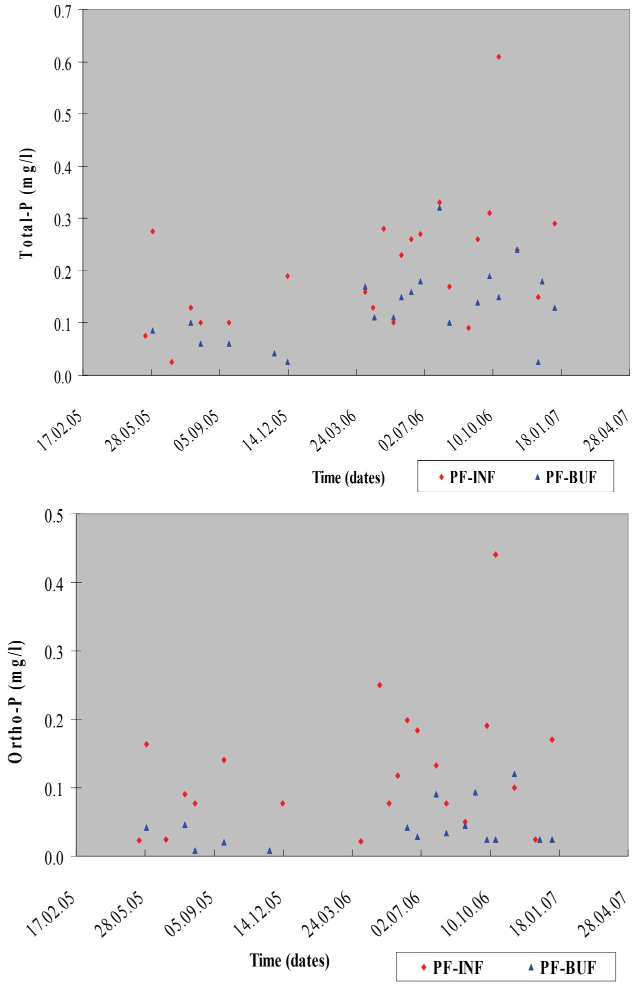


Fig.6 Effect of the buffer on removal of TP and Ortho-P

The buffer had the primary purpose of being used as a storage reservoir for PF-1, however the buffer reservoir went beyond its purpose for storage and became an integral part of P-removal system. The effect of the buffer was established and **Fig. 6** indicates both removal of total phosphorus and ortho phosphorus in the buffer. This was visualized in relation to the biological activities that the buffer may be under going. Algae outbreak in the reservoir buffer was attributed to be part of the phosphorus uptake in the reservoir buffer. Alternating anaerobic/aerobic process at the bottom of the buffer (due to sedimentation) will induce phosphorus uptake and release.

(4) Removal efficiency of phosphorus

The performances of the overall average removal efficiency of phosphorus (P) in all filters are high as shown in **Fig. 7.** Almost all filters have the removal efficiency between 75-85%. From this experiment it can also conclude that Buffer reservoir is also capable to remove the phosphorus up to 50 %.Filter 4d has the lowest removal efficiency (about 60%). This is due to the absence of iron shaving in the filter bed. At the beginning of the experiments, the filter adsorbs the phosphorus due to the naturally present in the sand.

Filter 4b operated with higher surface load, filter 3a and 3i for the short standing times, filter 4e having no reed and less iron shaving, filter 4g with higher iron shaving and filter 4h with no calcium carbonate show no significant difference in the removal efficiency of phosphorus.

4. CONCLUSIONS

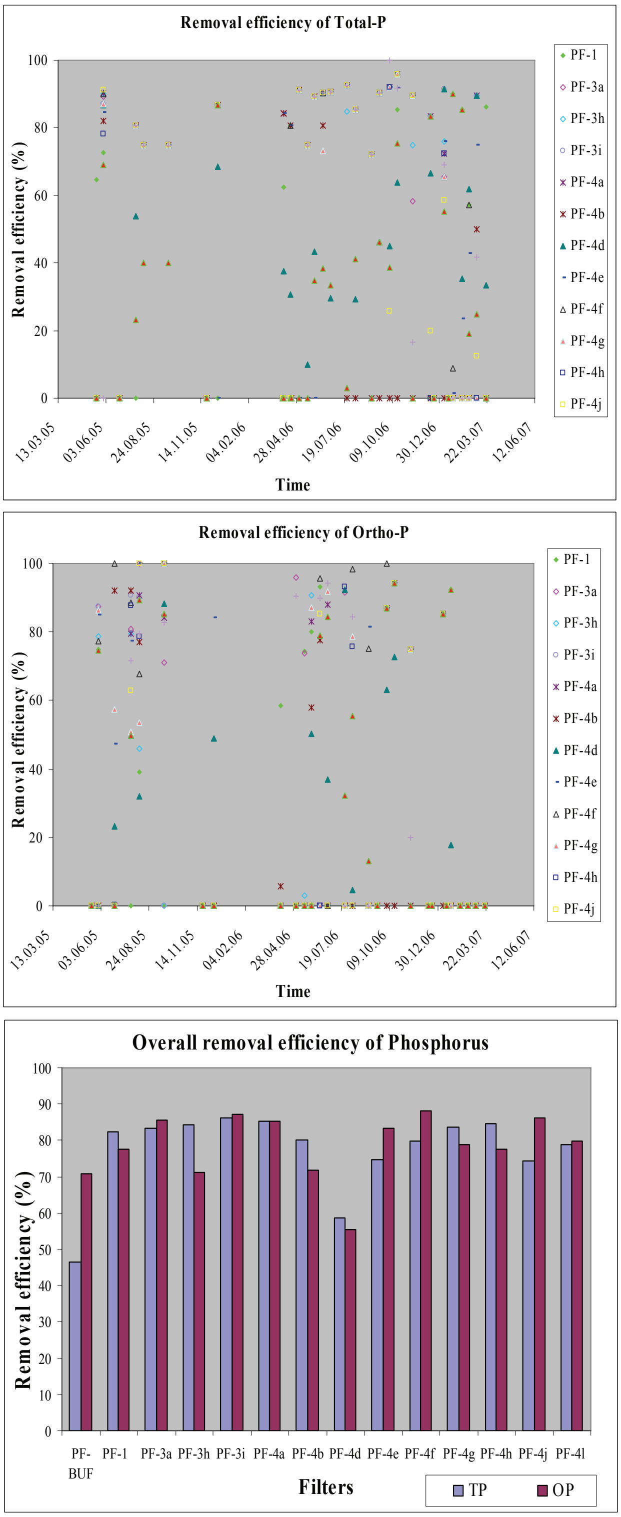


Figure 7 Overall average removal efficiency of TP and OP over the period of time

The following conclusions are made from this study:

1) Irons containing adsorbent mixtures are promising for the removal of phosphate.
2) The vertical reed bed filter is useful for the achievement of the optimum water quality by removing phosphate from the surface water for the recreational activities like: swimming, fishing and canoeing.
3) This results will be useful for the designing a model for optimization, maintenance and control of vertical flow reed bed filter for the further study. Based on the model a calculation of the investment cost, as well as a complete life cycle of a vertical flow reed bed filter can be calculated and predicted.
4) There is a high removal of dissolved TP* in the buffer reservoir. This might be due to the sedimentation and extreme growth of water plants.
5) The SLR has no influence on the treatment process and it is recommended that the average SLR of 0.15 m^3/m^2/day is maintained to avoid surface clogging.

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