# Performance evaluation of integrated treatment plant of trickling filter and constructed wetland

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**ABSTRACT**

A system consisting of trickling filter followed by a vertical intermittent flow constructed wetland system under laboratory condition was evaluated for the treatment of domestic wastewater. The system was able to produce final effluents with low concentrations of both organic and nutrients. Mean effluent concentrations were, respectively: BOD: 22.22mg/L;COD:64.58mg/L;SS:27.63mg/L;$NH_4$-N:0.62mg/L;P:1.72mg/L. The study shows that the integrated treatment system of trickling filter and vertical intermittent flow constructed wetlands can be effectively used a treatment option for a treatment with positive attributes of conceptual simplicity and lesser energy consumption.

## INTRODUCTION

The trickling filter reactors are widely recognized as an appropriate option for the treatment of domestic wastewater in tropical developing countries. The main advantages include simplicity, no mechanization, low sludge production and less energy consumption. However, trickling filters show lower removal efficiencies compared with other secondary processes, which brings about the need for a post treatment of their effluents, especially in terms of organic matter and nutrients. In order to improve water pollution control, removal of nutrients is of great importance. This fact has obviously influenced the water legislation in this field in many parts of the world (Haberl, 1999).

One of the most promising technologies for the post treatment of domestic wastewater is constructed wetlands, which preserve the attributes of conceptual simplicity, no mechanization and no energy consumptions.Vertical flow beds with intermittent flow are extremely reliable regarding removal of nutrients (Kayser *et al.,* 2005). Since wetland systems have been more studied when they are integrated with other treatment processes, it is believed that their performance and behavior as post treatment options for trickling filter effluent should be more investigated.

In this line, the study aims at investigating the performance of integrated trickling filter and vertical intermittent flow constructed wetlands treating the domestic effluent.

## MATERIALS & METHODS

The laboratory scale unit of vertical flow system (Figure 1) was fabricated with Fibre Reinforced Plastic (FRP). The trickling filter was made of FRP of size 30cm in diameter and 1.60m in height, filled with river stone of size ranging from 20 to 40mm. Fixed perforated distribution system was provided at the surface of the trickling filter to ensure even distribution. The wetland unit of dimension 1.0m x 0.6m x 0.6m was fitted with a sufficiently large drain pipe with valve to control flow and dashed plates to avoid erosion. The bed was prepared with layers of gravel: 3cm of particle size 10mm – 25mm, 10cm of particle size of 4mm – 6mm, 10cm of particle size of 2.5mm – 4mm followed by 10cm of coarse sand at the top of the unit. The distribution system consists of PVC pipes, with downside holes, at the top face of the unit, arranged symmetrically and proportionally to ensure even distribution of influent. The influent was fed to the pipe system at a height of 1.5m above the unit. A siphonic arrangement was set up at the inflow location so as to make the flow intermittent.

Fast drainage controls the height of the saturated zone and results in suction of fresh air to the unsaturated zone. Aeration is enhanced by the cyclic operation of inflow combined with fast drainage.

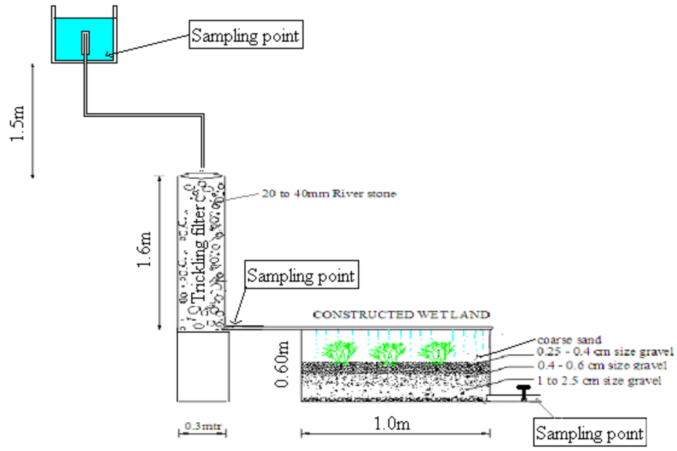


Figure 1–Integrated lab scale treatment unit of trickling filter and constructed wetland

The wastewater from the dosing tank allows influent to trickle through the distribution pipes over the filter media. This filtered water was then permitted to flow through the constructed wetland vertically and then collected through the control valve fitted at the bottom of the tank.

**Sampling and analyses**

Sample locations were provided in the

(i) Dosing tank,
(ii) Bottom of trickling filter tank and
(iii) Bottom of constructed wetland.

**Process Monitoring:** The wastewater samples collected from sample locations were analyzed for the following parameters:5-day Biochemical Oxygen Demand ($BOD_5$), Chemical Oxygen Demand(COD), Suspended Solids(SS),ammonia-N, nitrate-N , and total phosphorus and pH. All samples were analyzed as per the procedure outlined in Standard Methods (APHA, 2005).

RESULTS AND DISCUSSION

Experiments were carried out in the combined trickling filter and constructed wetland models and were operated for a period of 90 days. *Vertivaria sesmoida* species was used as a plant in the vertical flow reactor. Table 1 to Table 5 presents the influent concentration to the integrated unit and effluent concentration $BOD_5$, COD, SS, $NH_4$-N and Phosphate respectively through trickling filter and constructed wetland system. Based on influent/effluent concentrations to each unit, removal efficiencies of each unit operation and overall removal efficiencies have been calculated and are presented in respective tables. Table 6 presents the mean and standard deviation of the effluent concentration of investigated constituents such as $BOD_5$, COD, SS, $NH_4$-N and Phosphate. Based on the mean concentrations, mean removal efficiencies have been calculated and are presented in Table 7. The excellent performance in terms of organic matter and nutrients can be readily seen from the experimental results.

**Organic matter removal**

Fig 2(a) & Fig 2(b**)** presents the box- and –whisker plot of COD concentration along the system, and the removal efficiency in each unit. The sequential decrease of concentration is clear, and the contribution of each unit in the removal of COD can be easily seen. In terms of overall removal of COD achieved (88.66 %) the system showed a better performance and lower variability.

A detail of the performance of the wetland unit alone in terms of $BOD_5$ can be seen in the box-and-whisker plot in Fig 3(a) & Fig 3(b) which depicts influent and effluent concentrations from both the units, together with removal efficiency in each unit, allowing better comparison between each unit. There was excellent reduction in the $BOD_5$ in the effluent as observed by the results. The influent $BOD_5$ to the treatment plant varied from a low of 83.2mg/L to a high of 306.5mg/L. The $BOD_5$ of the final effluent varied from a low of 12.5 to a high of 29.5mg/L. Thus, the treatment plant effluent was well within the allowable $BOD_5$ limit of 30mg/L. The maximum $BOD_5$ reduction of around 92% is achieved through this system. As expected major removal efficiencies (> 80%) of organic matters occur at the trickling filter. In the vertical flow constructed wetland beds, removal efficiencies achieved for $BOD_5$ and COD were 33.31% and 37.44% respectively. Schonerklee *et al.,* (1997) reported that a COD removal efficiency of 50 to 60% was achieved through vertical flow beds. The lower efficiency in the present study may be due to low input value in constructed wetland and also due to less hydraulic retention time. It has been well established that percentage efficiency increases with increasing inflow concentration (Schierup *et al.*, 1990; Vymazal 1995). Brix, (1998) also reported that the concentration of $BOD_5$ and COD was largely dependent of inlet concentrations.

**Suspended solids removal**

Suspended solids removal efficiency was very good in constructed wetland system, whereas in trickling filter removal efficiency was low. Average value of SS removal efficiencies of 26.96% and 71.45% in trickling filter unit and constructed wetland were obtained. Fig 4(a) & Fig 4(b) presents the box plot of effluent concentrations and removal efficiencies, highlighting the performance in both units.

The vertical flow constructed wetland followed by a secondary treatment achieved high SS removal efficiency (72.74 to 80.77%) as a result of physical filtering by the gravel bed, enhanced by the filtering action of the organic deposits layer which accumulated at the surface. As noted by Boutin *et al*, (1997), this clogging layer remained self-managing with the action of reed stems and roots and with alternative feed and rest periods.

It can be observed from the results that the SS removal is around 80% through the system. The percentage removal by the trickling filter system varied from 24.47 to 28.57% with an average of about 26.96%. It is noted that the SS reduction is low through the trickling filter and it may be due to sloughing of slime layers attached with media. The removal through constructed wetland system having vertical flow varied from 61.84 to 74.59% with an average of 70%. As the regime of flow was vertical, the major removal mechanism may be filtration. The wetland system performed better than the trickling filter system in removing the suspended solids. The overall suspended solids removal by the entire treatment plant varied from 72.74 to 80.77% with an average of about 75.56%.

**Nitrogen removal**

Ammonia-nitrogen removal efficiency was only modest in trickling filter and removal efficiency was very good in vertical flow constructed wetland. Fig 5(a) & Fig 5(b) presents effluent concentrations of NH4-N and also the removal efficiency. $NH_4$-N of the raw wastewater varied from 11.0 to 30.8mg/l. The average concentration of $NH_4$-N in the raw influent wastewater was 21.64mg/l. The $NH_4$-N of the plant effluent varied from 0.25 to 0.85mg/l with an average of t 0.62mg/l. Thus, on an average the integrated treatment plant removed about 97% of $NH_4$-N. The ammonia removal through trickling filter was quite inconsistent. Sloughing of slime layer may be the reason for the inconsistency.

As expected the $NH_4$-N concentration generally decreased through the vertical flow constructed wetland system. The average $NH_4$-N concentration of the effluent from the constructed wetland system was 0.62mg/L. The $NH_4$-N removal by the constructed wetland system having vertical flow was about 96.66%. This high efficiency can be ascribed to the high oxygen transfer rate, as the flow was intermittent.

**Phosphorus removal**

Phosphorus removal took place in trickling filter and wetland, with mean removal efficiencies of 23.8% (Trickling filter) and 64.16% (Constructed wetland). Fig 6(a) & Fig 6(b) presents effluent concentrations of phosphate and also the removal efficiency

The average total P concentration of the raw wastewater was 6.3mg/L. The average total P concentration of trickling filter effluent was 4.8mg/L, which indicated that the trickling filter system removes total P in negligible amount. The average total P of the constructed wetland effluent was 1.72mg/L. The overall removal of total P through the integrated treatment plant was 72.74%, which was quite reasonable. Removal efficiencies between

27 and 65% were reported by Vymazal, (2002), and Mbuligwe, (2004) reached high removals (69 to 75%) in similar studies.

CONCLUSION

The integrated treatment plant removes on an average 88% of the incoming $BOD_5$ & COD and around 75% of SS. The nutrient removal, such as $NH_4$-N and total P, were above 97% and 72%, respectively. It is seen that the trickling filter with intermittent trickling flow is more effective in $BOD_5$ removal and constructed wetland having vertical intermittent flow is more effective in nutrient removal. The performance of the overall system was quite reasonable. These results are in accordance with the values reported for similar systems in Spain (Alvarez *et al.* 2008), providing further evidence of how an integrated treatment system improves the treatment performance and minimizes area requirement for the constructed wetland.

In the treatment of domestic sewage, different reactor configurations have been used by various researchers. One such study was carried out by Luiz *et al*, (1999) by the Association of Septic Tank and Constructed Wetland System for the treatment of domestic wastewater for small communities. The experiment was carried out in the Agriculture Secretary's Training Centre, Santa Catarina State, responsible for serving approximately 66 people daily, and was fed with local effluent. For carbonaceous pollution notable removal efficiencies were observed for both COD and $BOD_5$ parameter (more than 80%). In another study conducted by Surampalli *et al* (2007) by the associated overland flow and wetlands system, the overall average $BOD_5$ removal by the entire treatment plant was about 90%. The highest % removal was 96% and the lowest was 85%. The overall suspended solids removal by the entire treatment plant varied from 41.7 to 99.2% ( Surampalli *et al*, 2007). The Ammonia-N and phosphorus (P) removal were in the order of 96% and 63% respectively. Masi *et al.,* (2010) have tested several constructed wetland pilot systems with different pre-treatments in Egypt, Morocco, Tunisia and Turkey. Very efficient organic content reduction and nitrification (92-99%) was reported by them. These literature results are in fair agreement with the experimental results obtained in the present study.

Table 1. Influent and effluent concentration of $BOD_5$ & Removal efficiencies of trickling filter and CWs.

| No.of sample | $BOD_5$ mg/L | | | % Removal. (TF) | % Removal. (CW) | % Removal. (overall) |
|---|---|---|---|---|---|---|
| | 1* | 2 * | 3* | | | |
| 2 | 83.2 | 18 | 12.5 | 78.44 | 30.55 | 84.97 |
| 2 | 147.0 | 28 | 18 | 87.75 | 33.33 | 91.83 |
| 2 | 192.5 | 34 | 25 | 87.5 | 37.5 | 92.18 |
| 2 | 248. | 45 | 29.5 | 85.88 | 40 | 92.54 |
| 3 | 306.5 | 42.6 | 26.08 | 86.1 | 38.77 | 91.49 |

1* = Influent, 2* = Trickling filter effluent, 3* = Constructed Wetland Effluent

Table 2. Influent and effluent concentration of COD& Removal efficiencies of trickling filter and CWs.

| No.of samples | COD mg/L | | | % Removal. (TF) | % Removal. (CW) | % Removal. (overall) |
|---|---|---|---|---|---|---|
| | 1* | 2 * | 3* | | | |
| 2 | 243.02 | 59.68 | 35.47 | 75.44 | 40.55 | 85.40 |
| 2 | 447.0 | 67.72 | 41.76 | 84.85 | 38.33 | 90.65 |
| 2 | 492.5 | 91.11 | 57.85 | 81.5 | 36.5 | 88.25 |
| 2 | 759. | 129.94 | 81.60 | 82.88 | 37.2 | 89.24 |
| 3 | 906.8 | 167.75 | 106.23 | 81.5 | 36.67 | 88.28 |

1* = Influent, 2* = Trickling filter effluent, 3* = Constructed Wetland Effluent

Table-3. Influent and effluent concentration of SS& Removal efficiencies of trickling filter and CWs.

| No.of samples | SS mg/L | | | % Removal. (TF) | % Removal. (CW) | % Removal. (overall) |
|---|---|---|---|---|---|---|
| | 1* | 2 * | 3* | | | |
| 3 | 53.2 | 38 | 14.5 | 28.57 | 61.84 | 72.74 |
| 1 | 107.0 | 78 | 23 | 27.10 | 70.51 | 78.5 |
| 2 | 142.5 | 104 | 28.5 | 27.01 | 72.59 | 80 |
| 2 | 163.8 | 124 | 31.5 | 24.47 | 74.59 | 80.77 |
| 3 | 197.6 | 142.95 | 40.69 | 27.65 | 71.53 | 79.40 |

1* = Influent, 2* = Trickling filter effluent, 3* = Constructed Wetland Effluent

Table 4 . Influent and effluent concentration of $NH_4$-N & Removal efficiencies of trickling filter and CWs.

| No.of samples | $NH_4$-N mg/L 1* | 2* | 3* | % Removal. (TF) | % Removal. (CW) | % Removal. (overall) |
|---|---|---|---|---|---|---|
| 1 | 11.00 | 8.12 | 0.25 | 26.18 | 96.92 | 97.72 |
| 1 | 15.10 | 15.01 | 0.58 | 0.6 | 96.13 | 96.16 |
| 2 | 24.5 | 22.3 | 0.67 | 8.97 | 96.99 | 97.26 |
| 2 | 26.8 | 24 | 0.74 | 10.44 | 96.91 | 97.23 |
| 2 | 30.8 | 29.4 | 0.85 | 4.54 | 97.11 | 97.24 |

1* = Influent, 2* = Trickling filter effluent, 3* = Constructed Wetland Effluent

**Table 5** Influent and effluent concentration of $PO_4$-P & Removal efficiencies of trickling filter and CWs

| No.of samples | $PO_4$-P mg/L 1* | 2* | 3* | % Removal.(TF) | % Removal.(CW) | % Removal. (overall) |
|---|---|---|---|---|---|---|
| 1 | 3.2 | 2. 2 | 0.25 | 31.25 | 88.63 | 92.18 |
| 1 | 4.8 | 3.1 | 1.58 | 35.42 | 49.08 | 67.71 |
| 2 | 5.6 | 4.9 | 1.6 | 12.5 | 67.3 | 71.42 |
| 2 | 8.8 | 6.8 | 2.74 | 22.72 | 59.79 | 68.86 |
| 2 | 9.1 | 7.0 | 2.45 | 20.8 | 65.00 | 73.07 |

1* = Influent, 2* = Trickling filter effluent, 3* = Constructed Wetland Effluent

Table 6. Mean and standard deviation of the effluent concentration of trickling filter and CWs

| Constituent | Unit | Influent (Mean) | Std deviation | TF effluent | Std deviation | CW effluent | Std deviation |
|---|---|---|---|---|---|---|---|
| $BOD_5$ | mg/l | 195.44 | 77.09 | 33.52 | 9.85 | 22.22 | 8.03 |
| COD | mg/l | 569.66 | 235.45 | 103.24 | 40.44 | 64.58 | 26.21 |
| SS | mg/l | 112.82 | 53.39 | 97.39 | 36.68 | 27.63 | 8.72 |
| $NH_4$-N | mg/l | 21.64 | 7.41 | 19.77 | 7.42 | 0.62 | 0.13 |
| Phosphate | mg/l | 6.3 | 2.3 | 4.8 | 1.93 | 1.72 | 1.16 |

Table 7. Mean removal efficiency (%) of each unit and of the system as a whole.

| Constituent | Trickling filter | Constructed wetland | Trickling filter+cw |
|---|---|---|---|
| $BOD_5$ | 82.84 | 33.31 | 89.68 |
| COD | 81.88 | 37.44 | 88.66 |
| SS | 26.96 | 71.45 | 75.56 |
| $NH_4$-N | 8.64 | 96.66 | 97.13 |
| Phosphate | 23.8 | 64.16 | 72.74 |

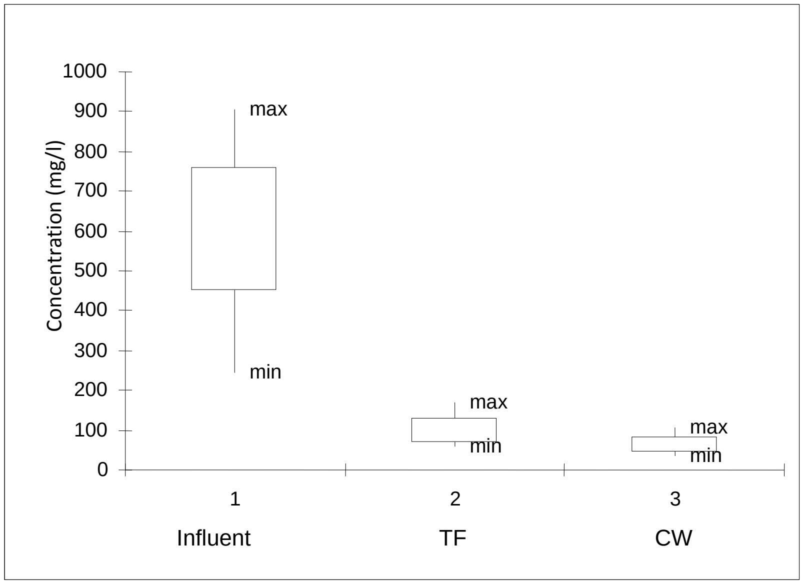


Figure 2(a) COD concentration along the treatment line

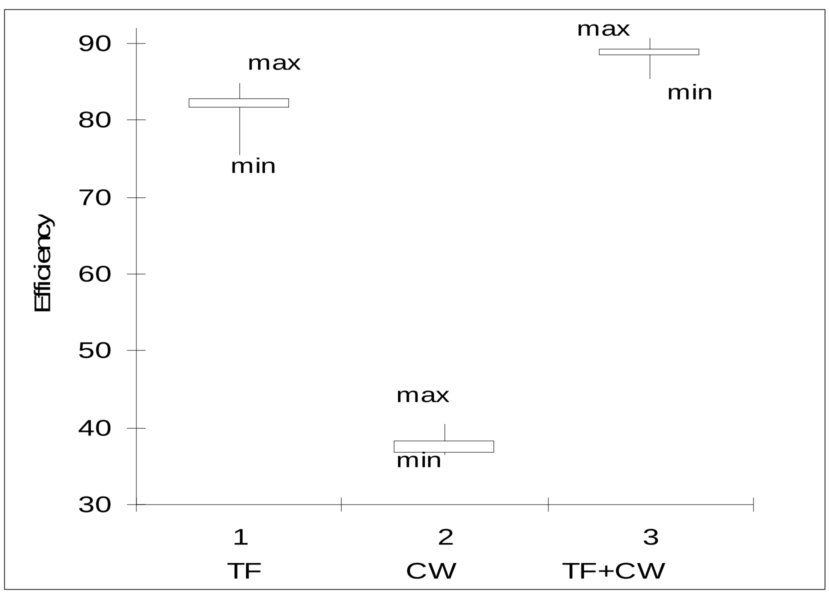


Figure 2(b) COD removal efficiencies in each unit and in the overall system

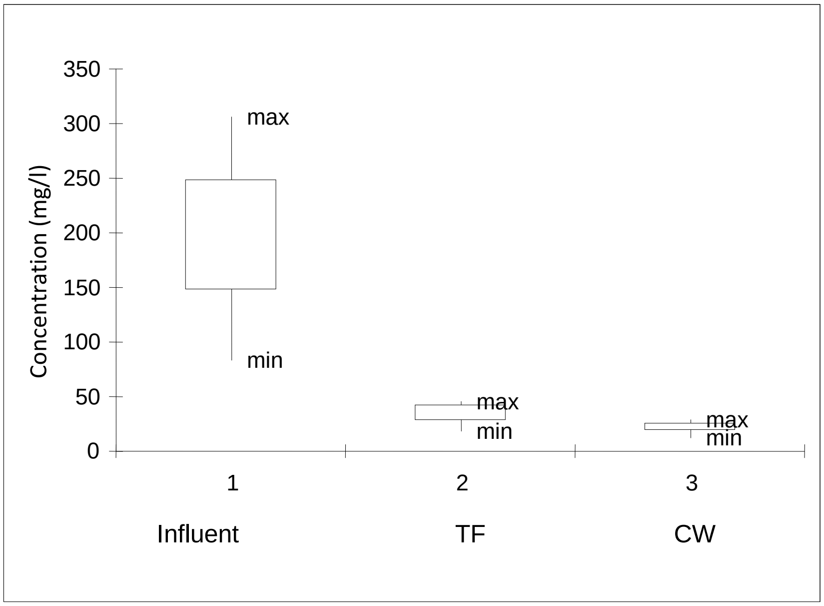


Figure 3 (a) BOD5 concentration along the treatment line

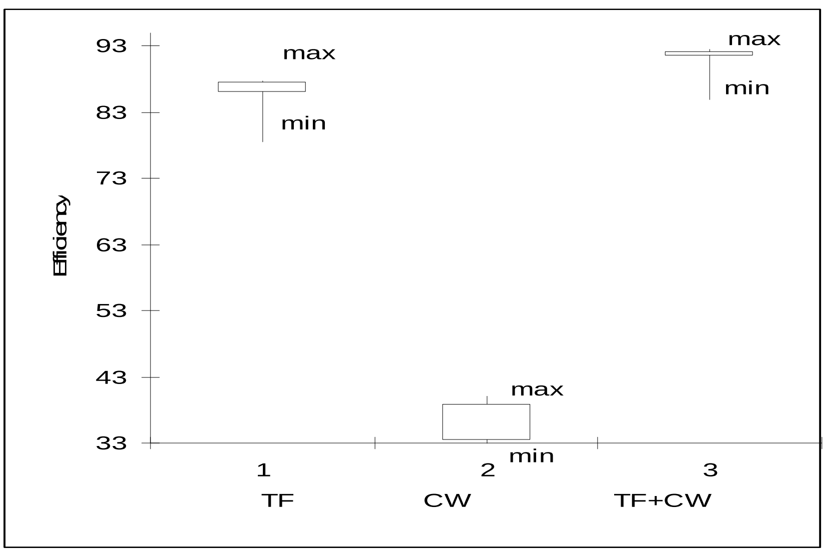


Figure 3. (b) BOD removal efficiencies in each unit and in the overall system

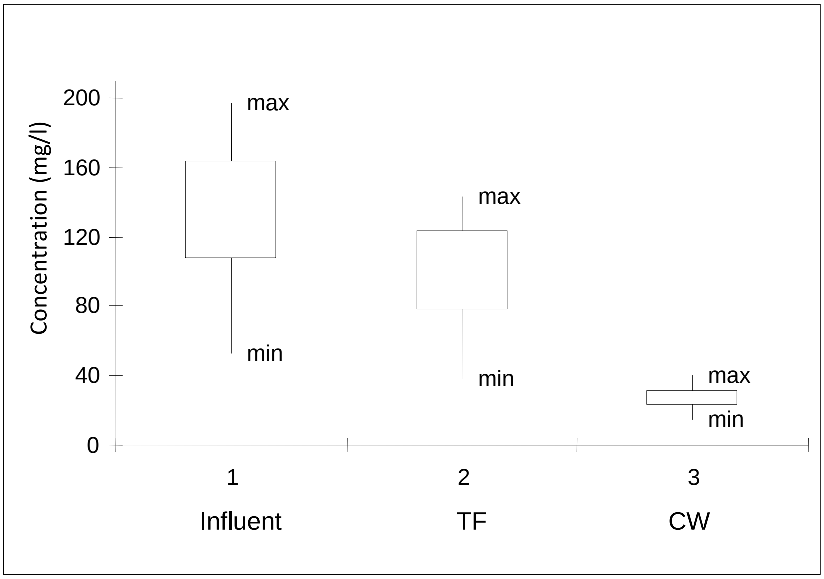


Figure 4 (a) SS concentration along the treatment line

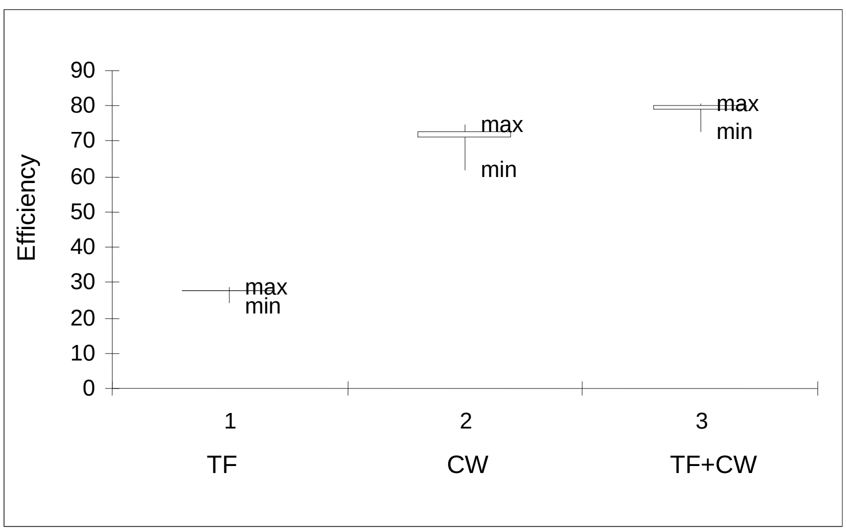


Figure 4 (b) SS removal efficiencies in each unit and in the overall system

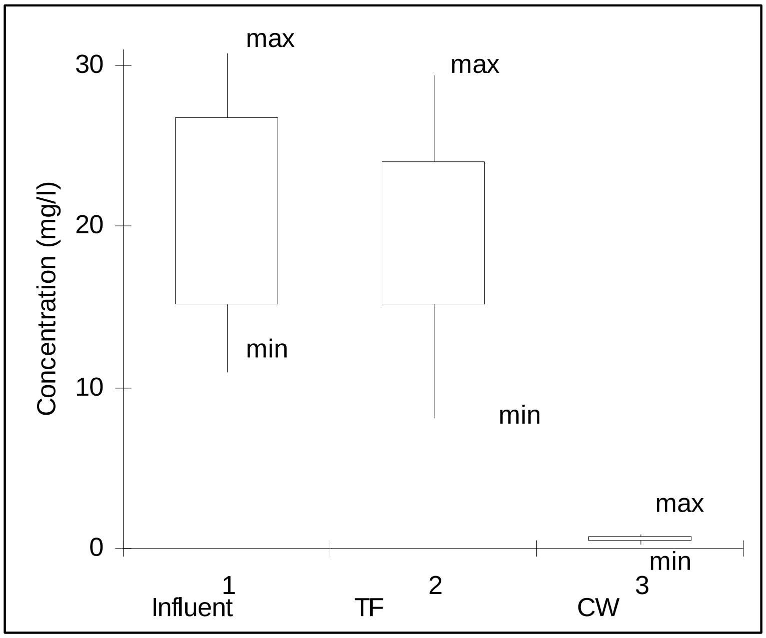


Figure 5(a) $NH_4$-N concentration along the treatment line

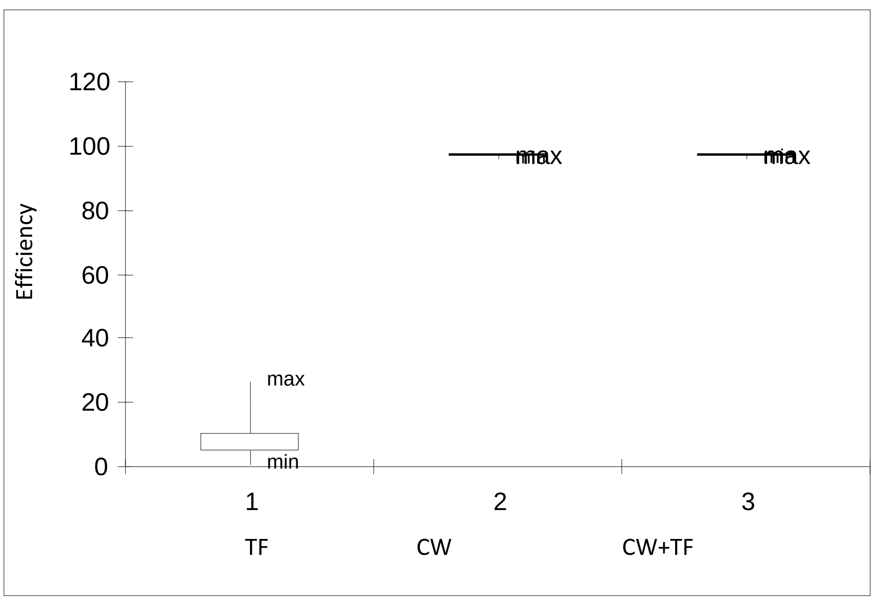


Figure 5 (b) $NH_4$-N removal efficiencies in each unit and in the overall system

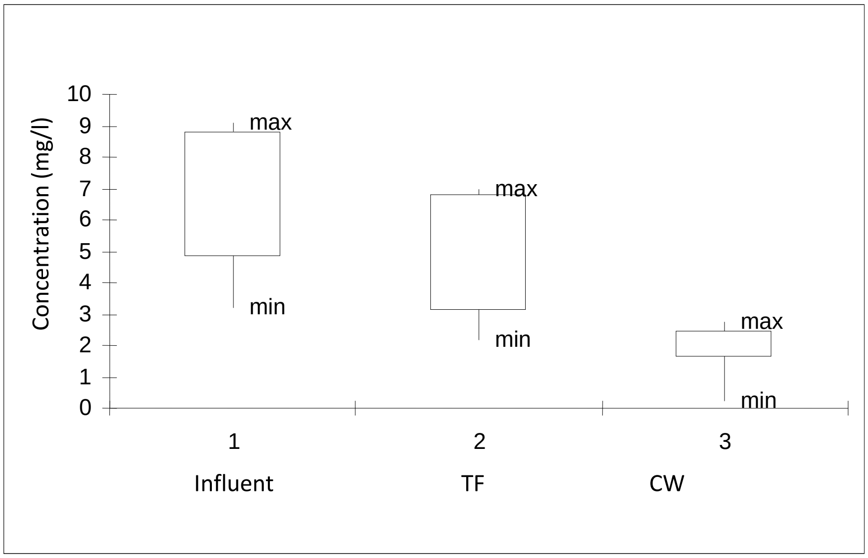


Figure 6(a) Phosphate concentration along the treatment line

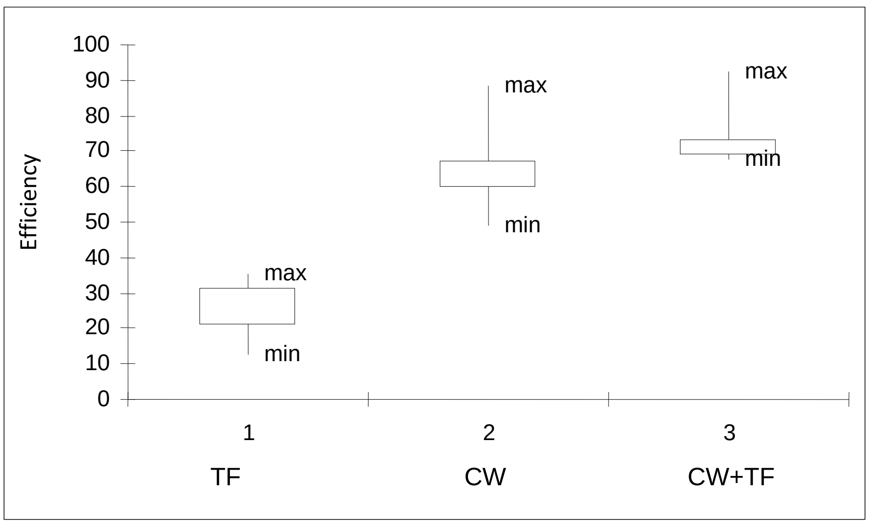


Figure 6 (b) Phosphate removal efficiencies in each unit and in the overall system

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