Effect of entrance shape on the performance of constructed wetland

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Abstract: In order to investigate the effect of entrance shape on the performance of free water surface (FWS) and subsurface flow (SSF) constructed wetlands treating wastewater, four pilot-scale units were constructed and operated continuously in parallel experiments. For this study the treatment scheme consisting of filtration unit followed by constructed wetland unit (FWS or SSF). Two different shapes of entrance were examined (rectangle and triangle). The results indicated that the triangle shape entrance enhances the performance of constructed wetland in the term of COD, BOD, TSS, bacteriological indicators such as fecal coliform (FC), fecal streptococci (FS), *Pseudomonas aeruginosa* (PS) and Salmonellae (Sal.). The performance of FWS with triangle entrance for removal of COD, BOD and TSS was more than 73, 83 and 81%, respectively. FC, FS and PS were removed by 10^4, 10^3 and 10^2 MPN/100 ml, respectively. While Salmonellae was removed completely. [Journal of American Science 2010; 6(9):787-795]. (ISSN: 1545-1003).

Keywords: Constructed wetland, bacteriological indicators, entrance shape

1. Introduction

Most of the arab countries are located in arid and semi-arid zones known for their scanty annual rainfall, very high rates of evaporation and consequently extremely insufficient renewable water resources. Sustainable management of water resources is a must as water scarcity is becoming more and more a development constraint impeding the economic growth of many countries in the region (Weshah, 2002). Water shortage is an important factor for establishing new industries as well as expansion of a certain high rate water consumption process. Now, there is a need for greater attention on water resources planning and development (Shiklomanov, 1998). An efficient plan should be developed considering all related issues, adverse climatic condition, limited water resources, high population growth, desertification and urbanization, rapid industrial growth, soil salinity, environmental sustainability, imbalance between economic development and water availability (Khan et al., 2009).

To close the gab between demand and supply, non-conventional water resources have to be developed. One of these resources is domestic wastewater. Hence, reclaimed wastewater is an interesting non-conventional resource envisaged to reduce water shortage especially in arid areas (El-Gohary et al., 1995). The deteriorating environmental situation in many developing countries encouraged investigations into the suitability of low-cost technologies such as constructed wetlands (El-Khateeb et al., 2009). The use of wetlands to treat effluent is not a new idea. Thousands of years ago, natural wetlands were used by the Chinese and by the Egyptians to clarify liquid effluent. However, the first "Constructed" wetland was not used until 1904 (in Australia). Even after that the use of such wetlands was slow to catch on. The first botanical treatment of waste was not reported in Europe until the 1950s; America's research into the field did not begin until the 1970s. Nevertheless, it is now recognized that constructed wetlands are an economic way for treating wastewater (Zurita et al., 2009).

The hydrology of wetlands is generally one of slow flows and either shallow waters or saturated substrates. The slow flows and shallow water depth allow sediments to settle as the water passes the wetland. The slow flows also provide prolonged contact times between the water and the surfaces within the wetland (EPA, 1993). The complex mass of organic and inorganic materials and the diverse opportunities for gas/water interchanges faster a diverse community of microorganisms that break down or transform a wide variety of substances (Cristina et al., 2009). Most wetlands support dense growth of vascular plants adapted to saturated conditions. This vegetation slows the water, creates micro environments within the water column, and provides attachment sites for the microbial community. The litter that accumulates as plants die back in the fall creates additional material and exchange sites, and provides a source of carbon, nitrogen, and phosphorous to fuel microbial processes (Hench et al., 2003).

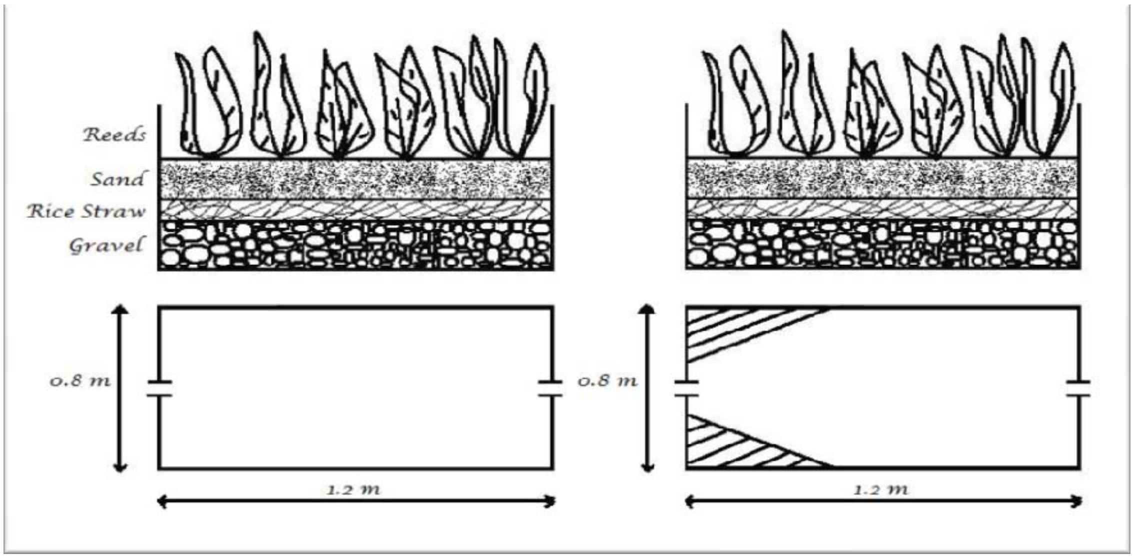
The aim of this work is to provide guidance to policy makers and planners on the potential of constructed wetlands operation and performance. Experiments have been operated and comissioned in Zenin wastewater treatment plant WWTP in Giza Governorate, Egypt.

2. Material and Methods

Model Description and operation

The influent water is the primary treated domestic wastewater (passed by primary treatment unit in Zenin WWTP). The primary treatment is sedmintaion treatment.

The primary treated wastewater was passed through filtration unit, which contains fiber and rice straw (1:1) layers of filtration from top to bottom; 20 cm gravel, 30 cm rice straw and 10 cm fiber. Two different models representing two different types of constructed wetland were constructed, to compare their results. The inlet was different in shape in the models. A schematic diagram of wetland is presented in Figure (1 A and B).



Rectangular shape entrance **Triangular shape entrance**

Figure 1: Schematic diagrams for the dimensions of thewetland system.

The layers of the materials used in the system were as follows:

Gravel	10cm
Rice straw (thin layer)	5cm
Sand	10cm

The experiment was carried out using the two main types on CWs, the free water surface (FWS), and the sub surface water flow (SSF). The experiment was carried out in two runs:

Run One: FWS1 with triangular water entrance.
Run Two: FWS2 with rectangular water entrance.
Run Three: SSF1 with triangular water entrance.
Run Four: SSF2 with rectangular water entrance.

Figure (2) Pilot model constructed wetland.

Calculations of Hydraulic Retention Time (HRT)
Calculations of flow rates and HRT of wetlands were based on Crites and Tchobanoglous (10).

$$Q = (A.d.\eta)/t$$

Where:
Q = flow rate (m^3/day)
A = surface area (m^2)
d = water depth of the system (m)
η = porosity of the system
t = detention time (day)
HRT = 2 days.

Wastewater Sampling and Analytical Methods
The performance of the treatment schemes was evaluated by monitoring the quality of the raw wastewater and effluents of each treatment unit. Analyses performed on these samples are pH, Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), Total Suspended Solids (TSS), total kjeldahl nitrogen (TKN.), Total Phosphorus (TP), Fecal Coliform (FC), Fecal Streptococci (FS), *Pseudomonas aeruginosa* (PS), Salmonellae (Sal.). These parameters were carried out according to Standard Methods for Examination of Water and Wastewater (2005).

Samples locations
The samples were collected from the following locations:

- Direct after primary treatment.
- After filtration
- After Constructed Wetland system

3. Results and Discussion
Influent wastewater characteristics
The concentration of COD, BOD and TSS was ranged from 351 to 453, 118 to 145 and 58 to 72 mg/l with average of 405, 154 and 65 mg/l, respectively. While, the average concentration of TKN and TP was found to be 29 and 3.2 mg/l (Table 1).

Table (1) Influent wastewater characteristics.

COD	BOD	TSS	TKN	TP	FC	FS	PS	Sal.
mgO_2/l	mgO_2/l	mg/l	mg/l	mg/l	MPN/100 ml	MPN/100 ml	MPN/100 ml	MPN/100 ml
405	154	65	29	3.2	$1.2x10^8$	$1.3x10^7$	$1.2x10^5$	$1.7x10^4$

The FC and FS densities were ranged from $1.6x10^7$ to $2.6x10^8$ and from $2.5x10^5$ to $4.8x10^7$ with average of $1.2x10^8$ and $1.3x10^7$ MPN/100 ml, respectively (Table 1). The average density of PS and Sal. was $1.2x10^5$ and $1.7x10^4$ MPN/100 ml, respectively.

Filtration process efficiency
It was noted that the level of COD, BOD and TSS was reduced from 405, 154 and 65 to 292, 99 and 43 mg/l with corresponding removal value of 33%, 37 and 40%, respectively (Figure 3). The density of FC, FS, PS and Sal. was reduced form $1.1x10^8$, $1.8x10^7$, $1.8x10^5$ and $2x10^4$ to $1.1x10^6$, $1.6x10^5$, $1.2x10^3$ and $4.4x10^2$ MPN/100 ml, respectively (Figure 4).

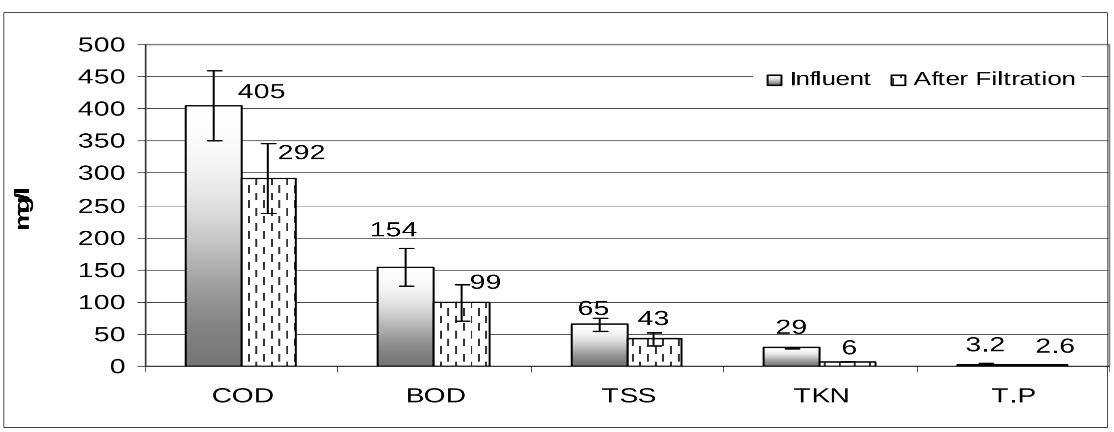


Figure (3) Efficiency of filtration process for the removal of COD, BOD, TSS, TKN and TP.

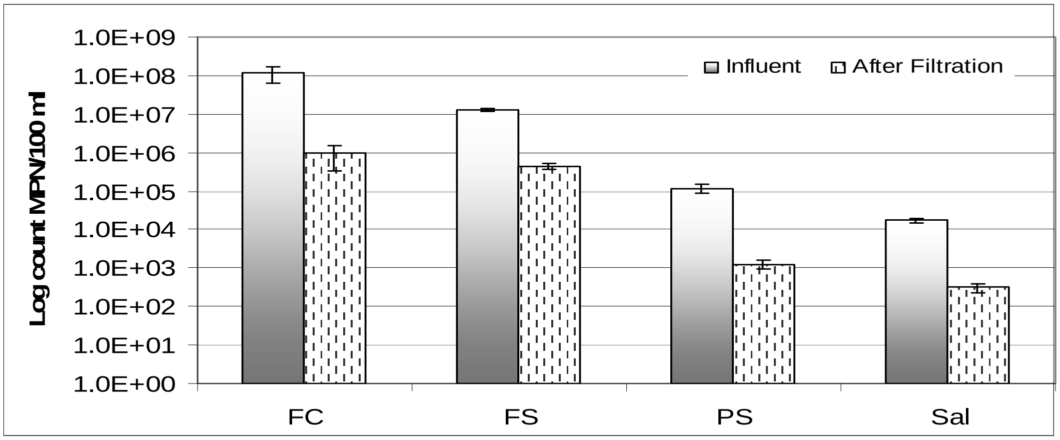


Figure (4) Efficiency of filtration process for the removal of FC, FS, PS and Salmonella.

The effluent from filtration process is usually not complying with the standards for treated effluent reuse (12). Therefore, an adequate polishing step is required.

Run One: FWS 1 with triangular water entrance

The effluent from the filtration was treated using wetland system.

The level of COD, BOD and TSS was reduced from 292, 99 and 43 to 95, 23 and 12 mg/l, the corresponding removal efficiency was 68, 77 and 72%, respectively (Figure 5). The BOD/COD ratio was reduced from 0.3 (after filtration) to 0.2 in the wetland effluent. The level of TKN and TP was decreased from 6 and 2.6 to 3 and 1.1 mg/l, with removal efficiency of 54 and 57%, respectively.

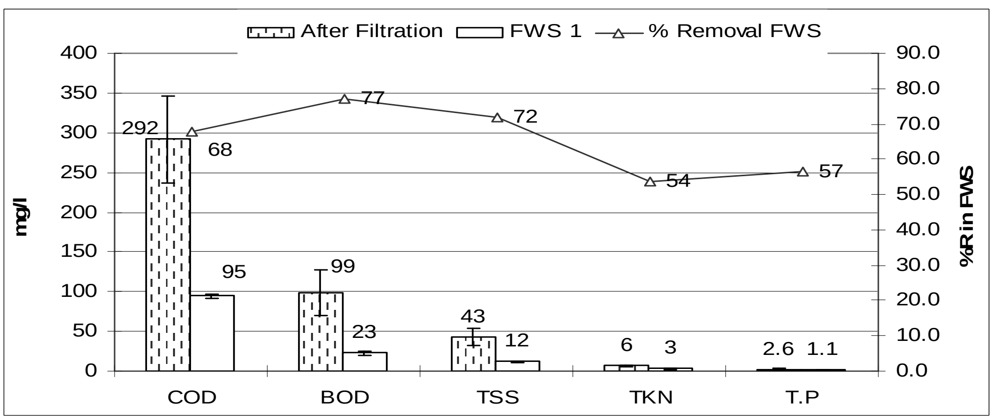


Figure (5) Efficiency of FWS 1 with triangular water entrance for the treatment of wastewater.

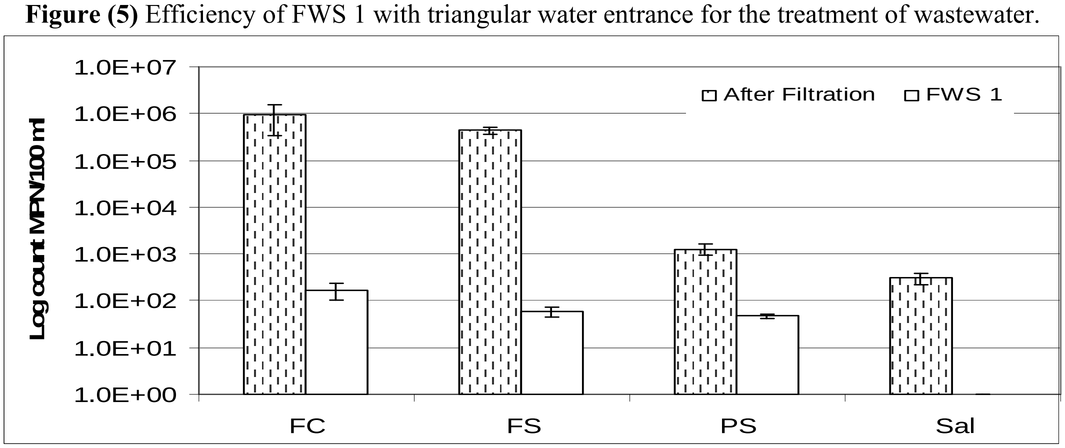


Figure (6) Efficiency of FWS 1 with triangular water entrance for the removal of some selected bacteriological strains.

Figure (6) shows the performance of FWS for the removal FC, FS, PS and Salmonellae. The densities of FC, FS and PS were reduced from $1.1x10^6$, $1.6x10^5$ and $1.2x10^3$ to $1.7x10^2$, $1x10^2$ and 4.7x10 MPN/100 ml. Sal. was completely removed during this step of treatment (Figure 6).

Run Two: FWS 2 with rectangular water entrance.

Figure (7) shows the performance of FWS with flat water entrance for the treatment of wastewater. The level of COD, BOD and TSS was reduced from 292, 99 and 43 to 119, 36 and 19 mg/l with corresponding removal efficiency of 59, 64 and 55%, respectively.

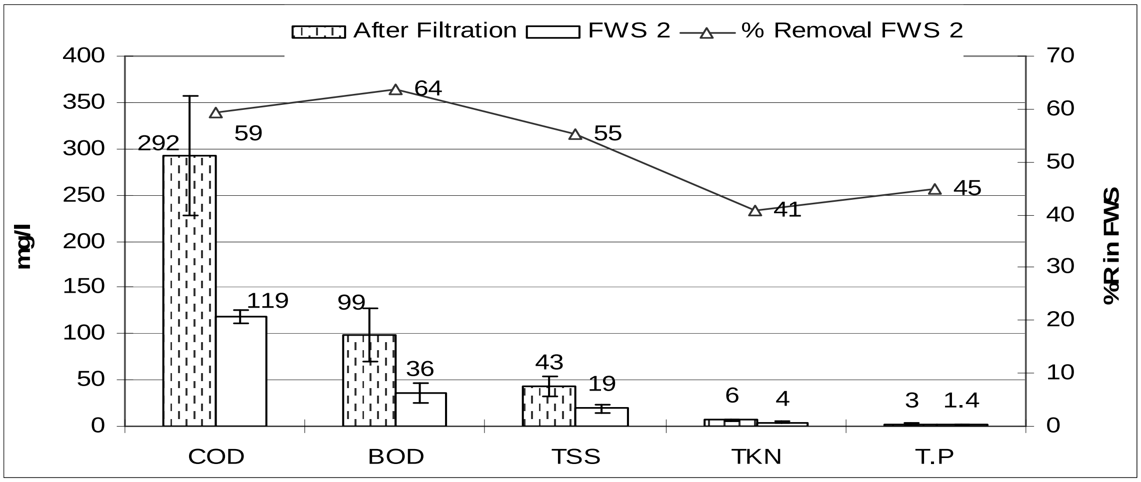


Figure (7) Efficiency of FWS 2 with triangular water entrance for the treatment of wastewater.

Figure (8) shows the removal rate of FC, FS, PS and Salmonellae. It is clear that FC, FS and PS densities were reduced from $1.1x10^6$, $1.6x10^5$ and $1.2x10^3$ to $2.1x10^2$, $2.5x10^2$ and 8x10 MPN/100 ml. While, Salmonella was completely removed during this step of treatment.

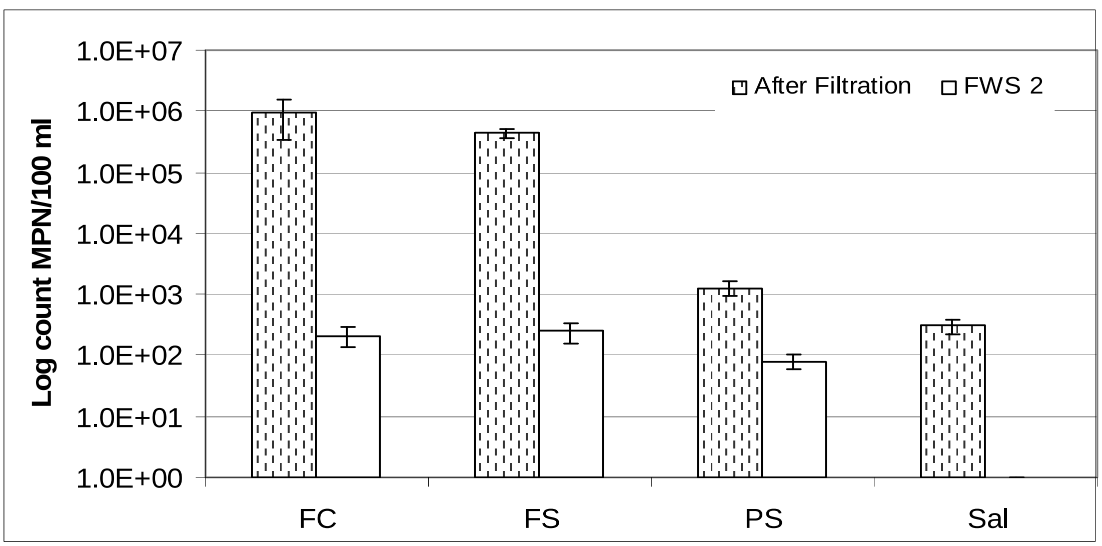


Figure (8) Efficiency of FWS 2 with triangular water entrance for the removal of some selected bacteriological strains.

Run Three: SSF 1 with triangular water entrance.

Figure (9) shows the performance of SSF 1 with triangular water entrance for the treatment of wastewater. The level of COD, BOD and TSS was reduced from 292, 99 and 43 to 125, 37 and 16 mg/l with corresponding removal efficiency of 57, 62 and 63%, respectively.

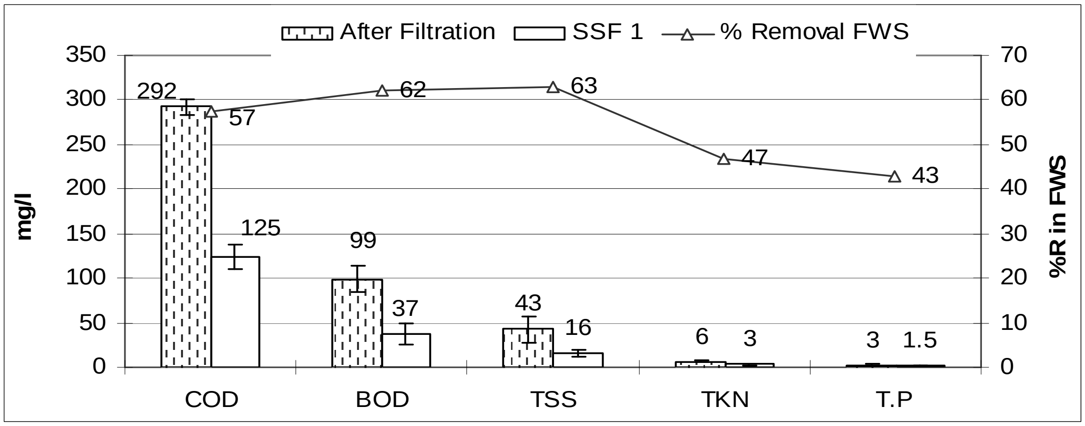


Figure (9) Efficiency of FWS with triangular water entrance for the treatment of wastewater.

Figure (10) reflects the efficiency of SSF 1 wetland for the removal of bacteriological indicators. The density of FC, FS and PS was reduced from $1.1x10^6$, $1.6x10^5$ and $1.2x10^3$ to $4x10^2$, 7.5x10 and 6.4x10. Salmonella was not detected in the effluent of SSF 1.

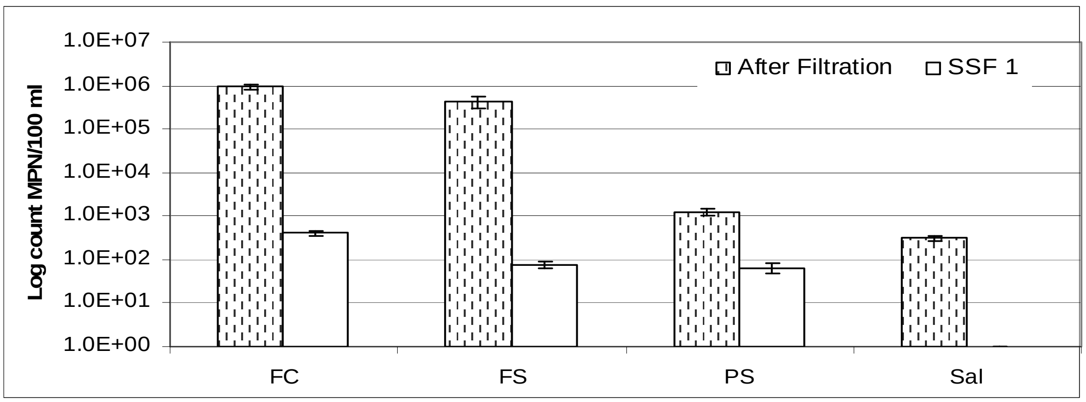


Figure (10) Efficiency of FWS with triangular water entrance for the removal of some selected bacteriological indicators.

Run Four: SSF 2 with rectangular water entrance. The concentration of COD, BOD and TSS 2 was reduced from 292, 99 and 43 to 137, 47 and 20 mg/l with removal rate of 53, 52 and 53%, respectively.

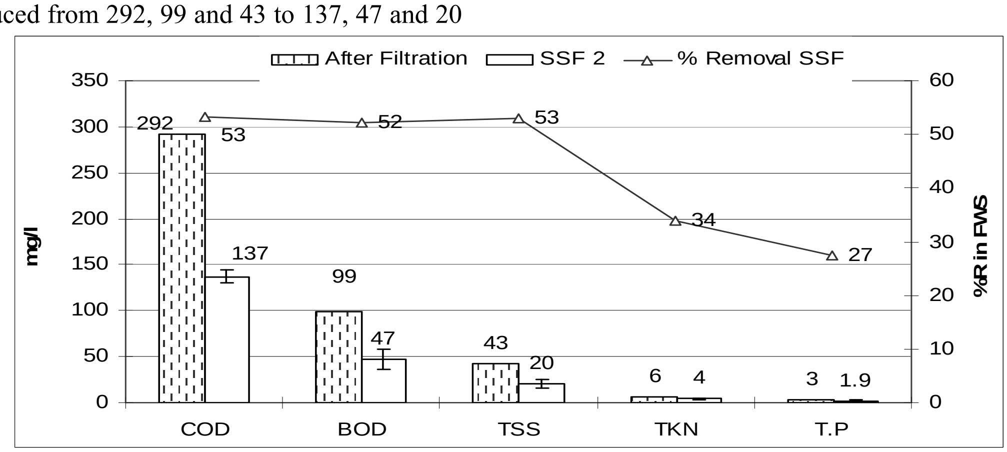


Figure (11) Efficiency of FWS with triangular water entrance for the treatment of wastewater.

Figure (12) shows the performance of SSF 2 wetland for the removal of bacteriological indicators. The density of FC, FS and PS was reduced from $1.1x10^6$, $1.6x10^5$ and $1.2x10^3$ to $1x10^3$, $1.8x10^2$ and 6.5x10. Salmonellae were not detected in the effluent of SSF 1.

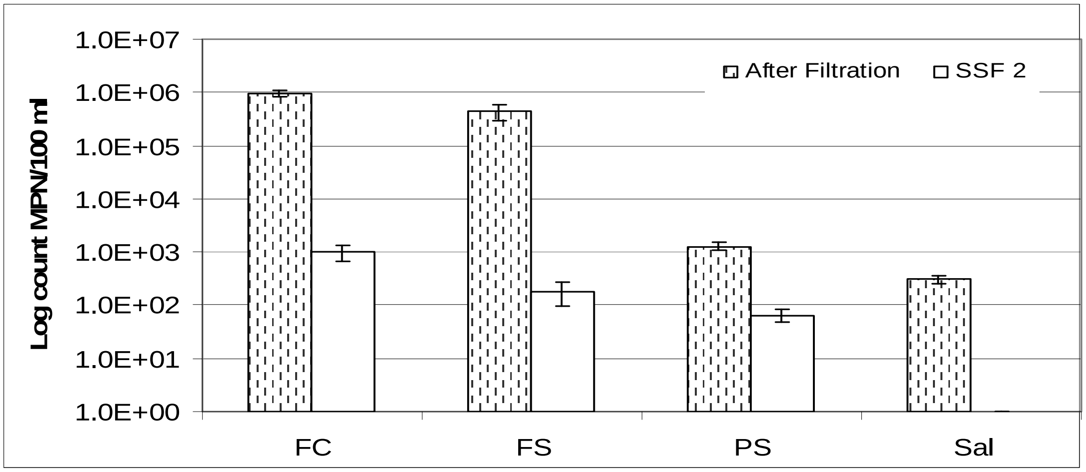


Figure (12) Efficiency of FWS with triangular water entrance for the removal of some selected bacteriological indicators.

Comparison between the systems

The results obtained indicate that the FWS 1 wetland is more effective in COD, BOD and TSS removal than the FWS 2 wetland. The mean residual COD, BOD and TSS in the FWS 1 wetland were 105, 23 and 12 mgO_2/l (Figure 13). This is due to the relatively low velocity and better distribution of the influent water than in the other systems. The wetlands act like horizontal gravel filter and thereby provide opportunities for TSS separations by gravity sedimentation, straining and adsorption on biomass film attached to gravel and root system and this can reduce the level of COD and BOD (EPA, 2000). Organic matter is decomposed in constructed wetlands by both aerobic and anaerobic microbial processes as well as by sedimentation and filtration of particulate organic matter (Vymazal and Kröpfelová, 2009). Phosphorus reduction in the wetland was higher 56% in the effluent of FWS 1 (Figure 13). This could be due to the presence of algae in the FWS wetland that can affect the concentrations of TP in the final effluent. El-Khateeb et al., (2009) and El-khateeb and El-Gohary (2003) concluded that there is a positive role of the plant in the uptake of phosphorus especially during the growing period of the plants. The narrow entrance (FWS 1 and SSF 2) enhance the flow of water and may reduce the short circuit which occurs when a large fraction of water traveling through a system exits well before the residence time, reduces the performance of constructed treatment wetlands (Lightbody et al., 2009; Kotti et al., 2010).

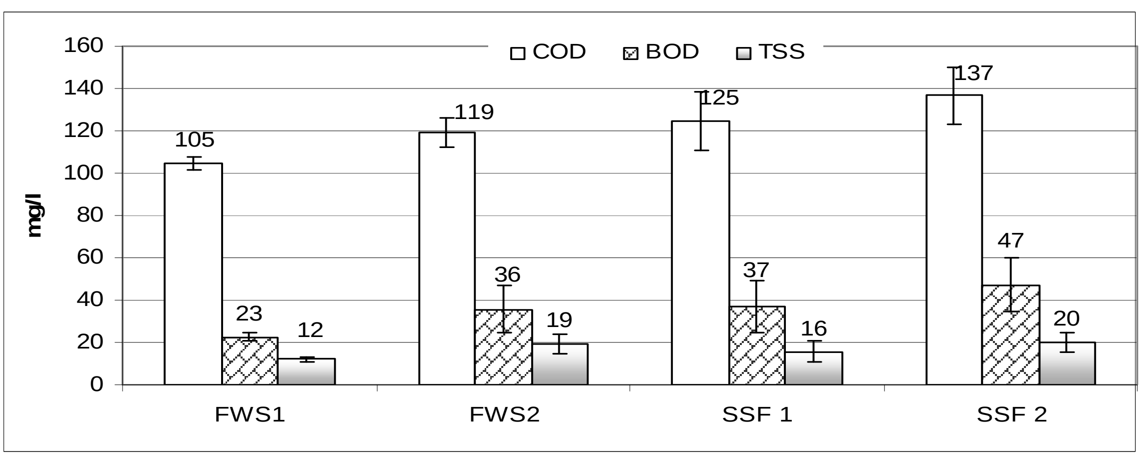


Figure (13) Comparison between the wetland systems used in the study.

In terms of the fate of indicators of pollution (FC, FS, PS and Sal.) in constructed wetland effluents, the results of this study showed a slight improvement in the case of FWS 1 wetland as compared to the other wetland systems (Figure 14). This could be attributed to the exposure to the sun ultra-violet ray action. These results were found to be in a good agreement with that reported by El-khateeb & El-Gohary (2003) and El-Khateeb et al., (2009).

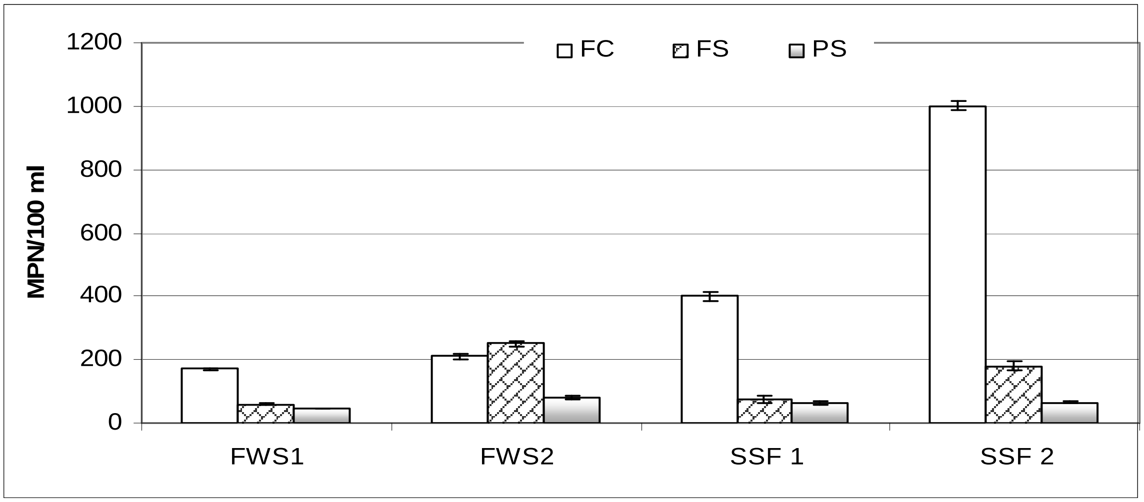


Figure (14) Efficiency of wetland systems for removal of indicator bacteria.

4. Conclusions

Results indicate that the design of the entrance has some effect on the performance of constructed wetland systems.

The wetland systems are feasible, efficient and cost-effective alternative technology to replace traditional secondary biological system for treating industrial wastewater.

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