ENHANCEMENT OF BILBEAS DRAIN WATER QUALITY USING SUBMERGED BIOFILTERS (SBS)

D. S. El Monayeri [a], N. N. Atta [b], S. El Mokadem [c], and E. H. EL Gohary [d]

[a] Prof., [b] Associate Prof., [c] Dr., [d] Eng.
Dept. of Environmental Engineering, Faculty of Engineering,
Zagazig University, El Zagazig, Egypt

ABSTRACT

Bilbeas drain is one of the polluted water streams in Egypt. The concentration of organic matter (COD) along the year 2001 ranged between 187 – 261 mg/L, and at the same time the concentration of the dissolved oxygen (DO) ranged between 0.01- 0.5 mg/L; which finally affects the stream self-purification capacity. One of the proposed methods to enhance the drain self-purification capacity is the use of submerged biofilter (SB). Four stream pilots were installed at 35.0 km of Bilbeas drain. Three of them were equipped with three different types of media working as SB while the fourth remained without any media. The three biofilters had the same total surface area of media for biofilm growth, the same width, and depth, but differed in length in the flow direction. The four streams were operated at the same time under the same flow rate. It was observed that the stream packed with *star shape* media achieved the highest % of increase of COD removal rates over natural purification at the same equivalent length, and reached about 783.8%. This could be attributed to its smallest length in the flow direction, which allows slight treatment in the reference stream at an equivalent length to the biofilter. The % of increase achieved by the stream packed with *pall rings* media was 320.2%, whereas the lowest % of increase was achieved by the stream packed with *gravel* media, about 198.4% attributed to its longest length in the flow direction, which allowed for more treatment in the reference stream at an equivalent length compared to the other two biofilters.

Keywords: biofilters**,** biological media**,** COD removal, self-purification, water pollution

1INTRODUCTION

Water is a vital natural resource which is essential for a multiplicity of purposes; such as, domestic and industrial uses, power generation, agriculture, transportation, recreational uses (swimming, boating and aesthetic), fisheries, and ecological balance. Water pollution is commonly defined as any physical, chemical, or biological change in water quality. It adversely impacts living organisms in the environment and makes a water stream unsuitable for one or more of its beneficial uses.

It is well known that every water stream has an environmental self-purification capacity to purify itself from pollutants through a variety of physical (e.g. dilution, adsorption, sedimentation,…etc), chemical (e.g. oxidation, hydrolysis,...etc), and biological processes (biodegradation), Gehm, and Bregman, 1976. The complex of these processes is important for upgrading and maintaining the quality of water stream and for providing habitats for a number of aquatic species.

The discharge of different wastewater and residues of human and natural activities into water streams has several impacts. It may cause a decrease and even depletion of the dissolved oxygen and become dangerous on the natural balance of the river aquatic life. Also, the ability of self-purification to permit the re-establishment of the balance community decreases.

Improving self-purification capacity can take place just after the discharging point. This can be achieved by using the high rate biofilters (Mikio Hino, 1994), or submerged attached growth biofilters (SAGBs) (Abd El-Rahman, 2002).

The (SAGB)- or simply submerged biofilter (SB), is one of the most common types of fixed film reactors, in which the microorganisms; responsible for the conversion of organic matter in the wastewater to gases and cell tissue, are attached to some inert medium. A wide variety of media types can be used; such as rock, slag, or specially designed ceramics or plastic materials. Flow through media may be upward, downward or horizontally across the media.

The interest of SBs stems from the high biomass concentrations that can be achieved resulting in short hydraulic residence time (HRT) in comparison to suspended growth systems with equivalent solid retention time (SRT). This results from the use of media with high specific surface area (Water Environment Federation, 1997). This advantage makes the use of (SB) a suitable method for the enhancement of water quality in polluted streams.

The performance of biofilters in reducing the organic matter is influenced by several factors such as; wastewater composition (COD, DO, TSS, toxic,…etc), media specification and configuration (specific surface area, void ratio), organic volumetric loading rate (VLR), organic biofilm loading rate (BLR), solids retention time (SRT), hydraulic residence time (HRT), total hydraulic loading (THL), in addition to other factors including temperature and pH value.

The removal process of the biofilter is described by the first order kinetic theories. The effluent concentration of BOD can be estimated from the following equation (Mikio Hino, 1994):

$$L_e = L_i e^{\frac{-KVS}{Q}}$$

Where; *Li and Le*= the influent and effluent concentrations of BOD, *Q*= flow rate, *V*= volume of the biofilter, *S*= specific surface area of media, *K*= reaction rate constant.

The value of *K* depends upon media characteristics (configuration, specific surface area, void ratio, and surface roughness), wastewater composition, and temperature. The temperature of the wastewater rather than that of the air was found to be the controlling factor-particularly with high rate filters. And the effect of the wastewater temperature becomes less important as either the organic or the hydraulic loading becomes heavier (Water Pollution Control Federation et al., 1977). The value of *K* corrected for various temperatures by the following relationship:

$$K = K_{20} \times 1.035^{T-20}$$

Where; K_{20} *and* K = reaction rate constant at 20°C, and at any specified temperature (T).

In a previous study trials were made for removing or decreasing the concentration of organic matter from fresh water streams polluted with domestic waste water (Abd El-Rahman, 2002). During this study three different plastic media (plate settler, tube settler, and plastic balls) were used as biofilters. The results showed that the removal efficiency of BOD ranged from 50.6-66.0% in case of "Plate settler" , and about 58.4-73.0% in case of "Plastic balls" , and about 65.8-79.0% in case of "Tube settler", compared to 23.4-35% in case of "No media".

In the present work other trials were carried out for improving the water quality of Bilbeas drain. The aim of this work is to study the influence of using submerged biofilter on reducing the organic pollution content at the discharging point and determining the percentage of increase of stream self purification capacity by biofilter in comparison to natural stream self purification capacity.

METHODS AND MATERIALS

1. Stream Pilots

The experimental work was carried out by using four stream pilots installed at the berm of Bilbeas drain- at 35.0 km. Figure 1 shows a schematic diagram for the four stream pilots. Each stream has 40 m length, 0.38 m width, and a total side wall depth of about 0.75 m. Each stream was furnished by influent weir for measuring the influent discharge. Three diesel pumps were used to raise the wastewater from the drain to the pilots. Three pilots were equipped with three different types of media, and the fourth stream pilot was operated without any media in order to provide a corresponding reference for the natural stream self-purification.

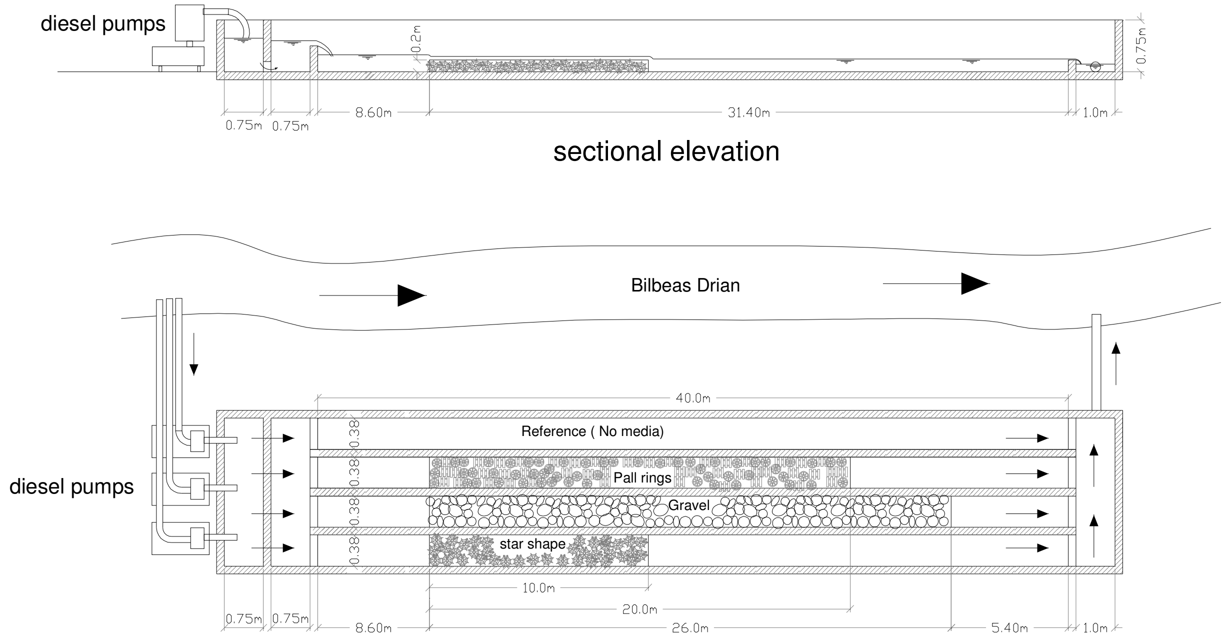
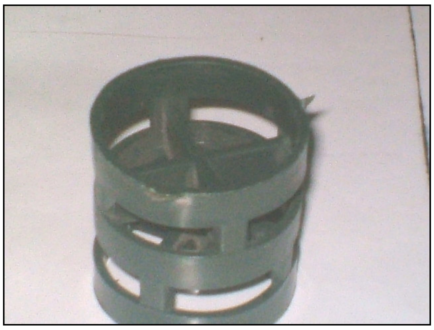


Figure 1 schematic diagram for the stream pilots

2. Support Media

The performance of biofilter depends upon the type of media used and its characteristics such as; specific surface area, void ratio, surface roughness, geometry and configuration. During this investment three different types of media were selected and used as biofilters. Table 1 shows their characteristics. Figure 2-a shows the first biofilter; which is made of random packed media defined as *pall rings*. It is a common random packing media that is used for both shallow and deep trickling filters. Each piece is a plastic cylinder with perforated walls and internal ribs. The second biofilter; as shown in Figure 2-b, is made of another plastic media, it is not a common packing media; however it has a high specific surface area of about 175.68 m^2/ m^3, and void ratio of about 87 %, it is defined as *star shape*. The third biofilter is made from gravel; although it has a low specific surface area and void ratio compared to the other two types of media, it used for its low cost. The used gravel had an effective size of 3.1-4.0 cm. As recommended in previous works on the biological filters using mineral media, the nominal size was in the range of 38 – 51 mm (Bruce, 1969, Learner, 1976).

For easy handling each medium was placed in boxes (0.37 width x 0.20 height x 1.0 m length) and then installed in the stream pilots with the specified dimensions as shown in figure 1 and according to the experimental program.



(a)

(b)

Figure 2: The plastic media used: a) pall rings, b) star shape

Table 1: characteristics of the three packing media used in the study

Characteristics	Pall rings	Star shape	Gravel
Material	PVC	PVC	gravel
Unit diameter	5.0cm	6.0cm	3.1-4.0cm
Unit height	5.0cm	1.5cm	-----
Unit surface area (cm^2/piece)	124.983	89.64	45.45
Specific surface area (m^2/m^3)	87.84	175.68	67.57
Porosity , %	87.1%	87.0 %	39.5 %

3. Wastewater

The wastewater used in this study was collected from Bilbeas drain, in which the water is a mixture of treated, untreated and partially treated domestic and industrial wastewaters and agricultural runoff (Public Work Minster, 1996). During this study the concentration of organic matter or chemical oxygen demand (COD) and temperature were measured for all samples, whereas the concentration of total solids (TS), dissolved oxygen (DO) and pH-value were measured for some samples. All these parameters were measured according to the American Standard Methods for the Examination of Water and Wastewater. The value of chemical oxygen demand (COD) is one of the most important parameters in pollution control. In this study, COD is mainly measured instead of BOD. Because of a COD test takes from 2 to 3 hours to completed, where as a BOD test needs 5 days. Table 2 shows the characteristics of wastewater for all samples taken during the whole study.

Table 2: The physical and chemical proprieties of the wastewater during the whole study

Parameter	Values
COD	79 - 156 mg / l
TS	660 - 890 mg / l
DO	1.2 - 2.4 mg / l
pH-value	7.1 - 7.8
Water temperature	16 - 30 ^{o}C

4. Experimental Procedure

In this study the four pilots were operated at the same time. In order to provide the corresponding reference to the natural purification, the first stream was free from any media, as shown in Figure 1. In the second stream the *pall rings* biofilter was installed, in the third stream *gravel* biofilter was installed, and finally the *star shape* biofilter was installed in the forth stream.

Previous works were done to study the performance of submerged biofilters in treating wastewaters aerobically (Abd El-Rahman, 2002), and anaerobically (Tay et al., 1999). However, the comparison done between the different media used as biofilters was based on building the experimental pilots having the same volume, or having the same cross-sectional area and length, but differed in the total surface area of all pieces or units compound the biofilter.

In this study the comparison between the different media which compound the biofilters is based on having the same total surface area-for biofilm growth-of about 130m2, and the same cross-sectional area (0.2 m height x 0.37 m width), but differed in the whole volume, and length in the flow direction, as shown in Figure 1.

The experimental study was conducted in two stages. Stage "1" was carried out during winter (December 2005- March 2006). It included two runs. Stage "2" was done during summer (May 2006- July 2006) and also included two runs. The boundary operating conditions of both stages are displayed in table 3.

Table 3: The operational conditions applied through the whole study

Stage	Runs	Duration, days	Flow rate, L/s
1st	Start up period	30	As described in subsec. 2.6
	1st run	20	4.4
	2nd run	25	7.29
2nd	Start up period	30	As described in subsec. 2.6
	3rd run	20	8.9
	4th run	25	3.15

5. Samples Locations

Samples were taken from eleven locations. The (1^{st}) location is situated just after the inlet weir in the first stream, to determine wastewater characteristics at the inlet point for all streams. The (2^{nd}, 3^{rd}, and 4^{th}) Locations are taken at a distance of about 0.25 m upstream the media, to determine the wastewater characteristics just before the media. The (5^{th}, 6^{th}, and 7^{th}) Locations are taken at a distance of about 0.25 m downstream the media, to determine the performance of media and its effect on wastewater characteristics. Where as the (8^{th}, 9^{th}, 10^{th}, and 11^{th}) Locations were distributed along the reference stream at distances 8.35 m , 18.85 m , 28.85 m and 34.85 m respectively, to determine the variation in wastewater characteristics using natural self purification at equivalent lengths to the biofilters.

6. Startup of the Biofilters

In fixed film systems, such as aerated biofilters, several methods of start-up can be employed. The first method is the start-up of continuous reactors, initially operating as batch reactors followed by increasing the flow rates (Smith et al., 1990). The second method is done by using the process liquid at the nominal process flow rate, although start-up using a high nominal flow rate may take longer periods as reported by (Bacquet et al., 1991). A 30 days start-up period is recommended (Stephenson et al., 1998). Finally start-up may be carried out by seeding with activated sludge (Hamoda, 1987; Park and Ganczarczy, 1994).

The first method of start-up was used in stage “1”. The wastewater was flowing into streams and media for one hour at a rate of 4.4 L/s for about 10 days, and then flew continuously for 24 hours per day at the same flow rate for about 20 days. After a total start-up period of about 30 days, samples of the 1^{st} run were collected along 20 days, followed by another 25 days with an increase in the flow rate to 7.29 L/s for collecting the samples of the 2^{nd} run.

In stage “2” the second method of start-up was used. The wastewater flew into the streams and media continuously for 24 hours per day at a rate of 8.9 L/s for about 30 days as a start-up period. Samples of the 3^{rd} run were collected along 20 days, followed by another 25 days with a decrease in the flow rate to 3.15 L/s to collect samples of the 4^{th} run.

RESULTS AND DISCUSSION

During the whole study the four pilot streams operated continuously for 24 h/day at the same flow rate. The average water temperature was in the range of 16-20 ^{o}C during the 1^{st} run, and about 17-24 ^{o}C during the 2^{nd} run, and about 23-28 ^{o}C during the 3^{rd} run, and about 25-30 ^{o}C during the 4^{th} run. The COD removal ratios obtained by the three biofilters compared with “No Media” at the same equivalent lengths are shown in figures 3, 4, 5 and 6. The results show that the highest COD removal ratio was obtained by *pall rings* biofilter, and ranged between 19.6 % and 58.0% compared to 4.4% to 15.6% obtained at equivalent length in the channel with “No Media”. The COD removal ratio obtained by *star shape* biofilter ranged from 16.4% to 56.6% compared to 1.4% and 10.0% obtained at equivalent length with “No Media". The lowest COD removal ratio was obtained by *gravel* biofilter, and varied from 14.0% to 47.3% compared to 5.6% and 18.4% obtained at equivalent length with “No Media”.

It has been observed that the concentration of COD in each stream just before the media differed widely from one stream to another due to the installation of the media, and was affected by type of each medium and its configurations. This coincides with the previous studies (Abd El-Rahman, 2002). Because of this fact, the removal efficiency of COD for each biofilter was determined with respect to the COD conc. just entering the media.

The obtained results indicated that the use of submerged biofilters increase the COD removal efficiency compared to the natural stream self-purification. This refers to the fact that the natural purification depend upon the biological degradation of the organic matter by the suspended microorganisms present in the wastewater. On the other hand, the use of submerged biofilters provides two removal mechanisms of the organic matter; the first is the filtration action for a portion of the suspended organic matters from the water passing through the media. The second is the biological degradation of the organics by the attached microorganisms, which grow attaching to the media. It is well known that the suspended growth biological treatment systems are affected by the hydraulic retention time (HRT) which may ranging from several hours (as in the case of activated sludge systems) to several days (as in the case of lagoons and oxidation ponds) (Sundstrom et al., 1979). In this pilot study the HRT was nearly several minutes, so the removal ratio of COD by natural purification decreased compared to the biofilters. The performance of submerged biofilters is not affected by the HRT as long as VLR and THL. This is because the amount of biomass in the system is determined by the surface area of the media provided and other operating factors, not the length of time that the flow remains in the reactor.

Figure 7 shows a graphical comparison between the three biofilters in COD removal efficiency during the whole study. It was observed that the stream packed with *pall rings* media achieved COD removal ratio of about 56% and that of *star shape* biofilter achieved 51% compared to 46% removal ratio achieved by gravel biofilter, despite having the same total surface area, width, and depth. This is refers to the fact that the gravel media has a small void ratio (39.5%) compared to 87.1% for *pall rings* and 87.0% for *star shape* biofilters, which allows small portion of water to pass through the media and the large portion to pass over the media without treatment.

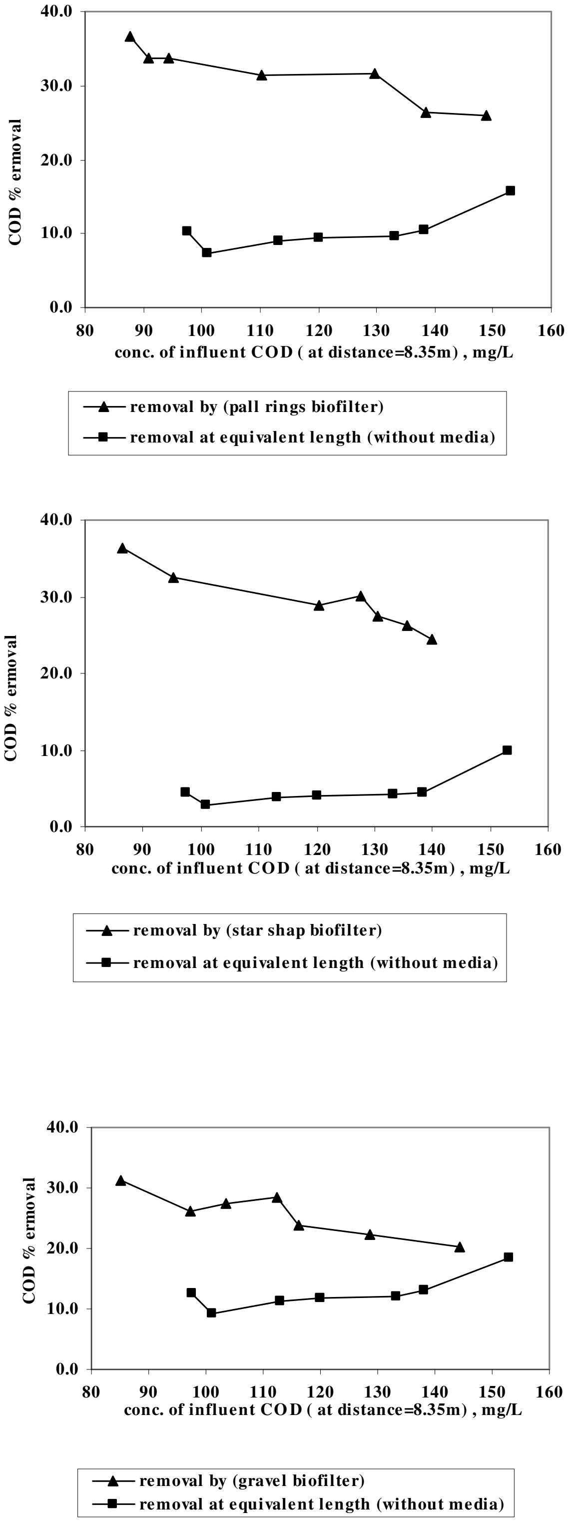


Fig. 3. Removal efficiency of COD by three biofliters compared to "No Media" (1st run - Q= 4.4 L/s)

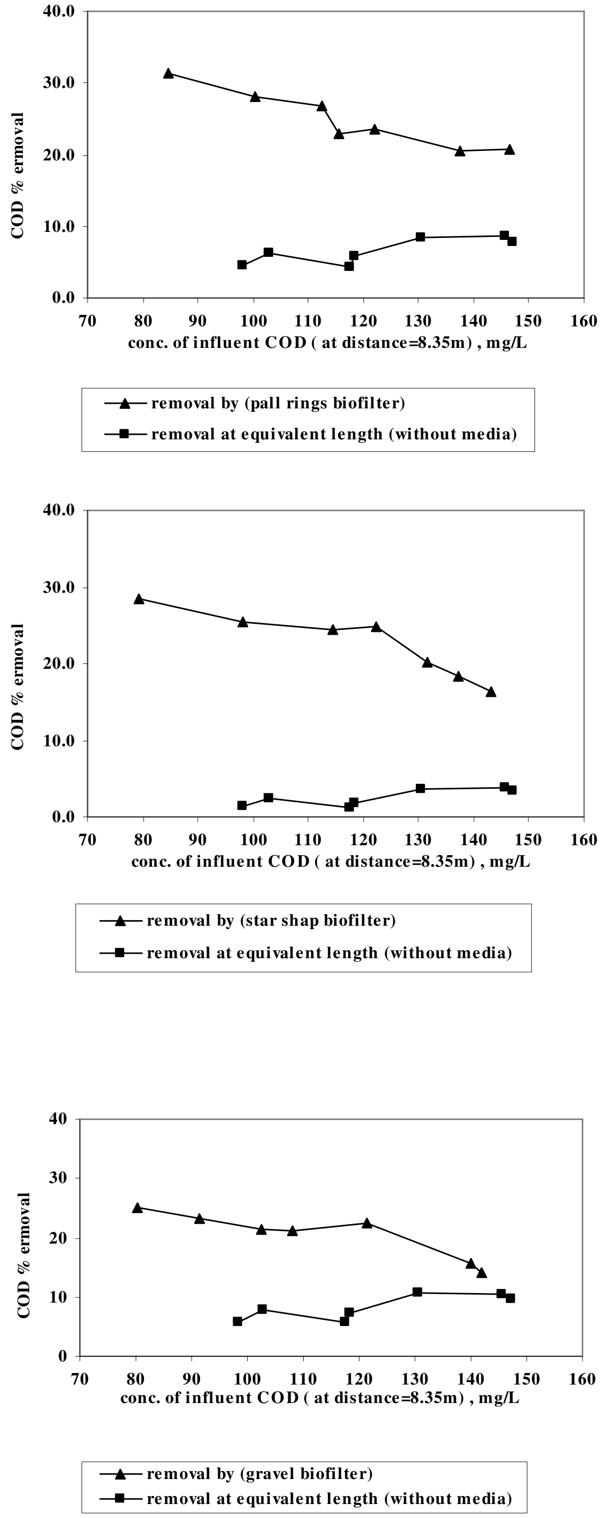


Fig. 4. Removal efficiency of COD by three biofliters compared to "No Media" (2nd run - Q= 7.29 L/s)

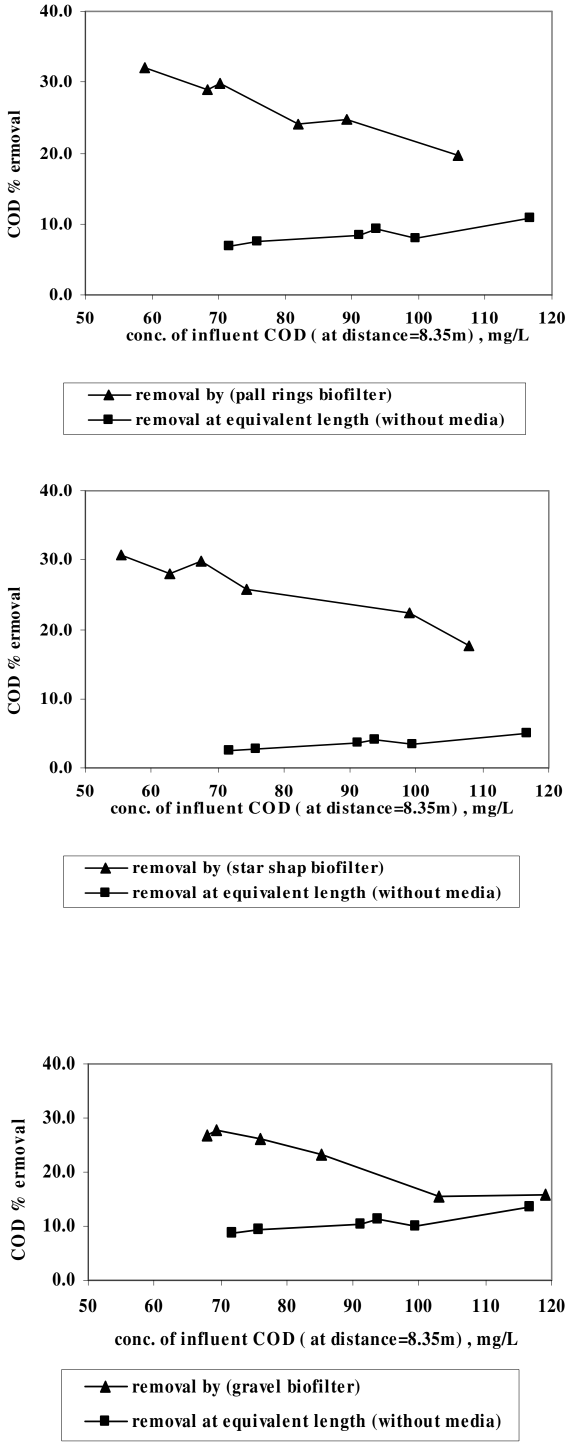


Fig. 5. Removal efficiency of COD by three biofliters compared to"No Media" (3rd run - Q= 8.9 L/s)

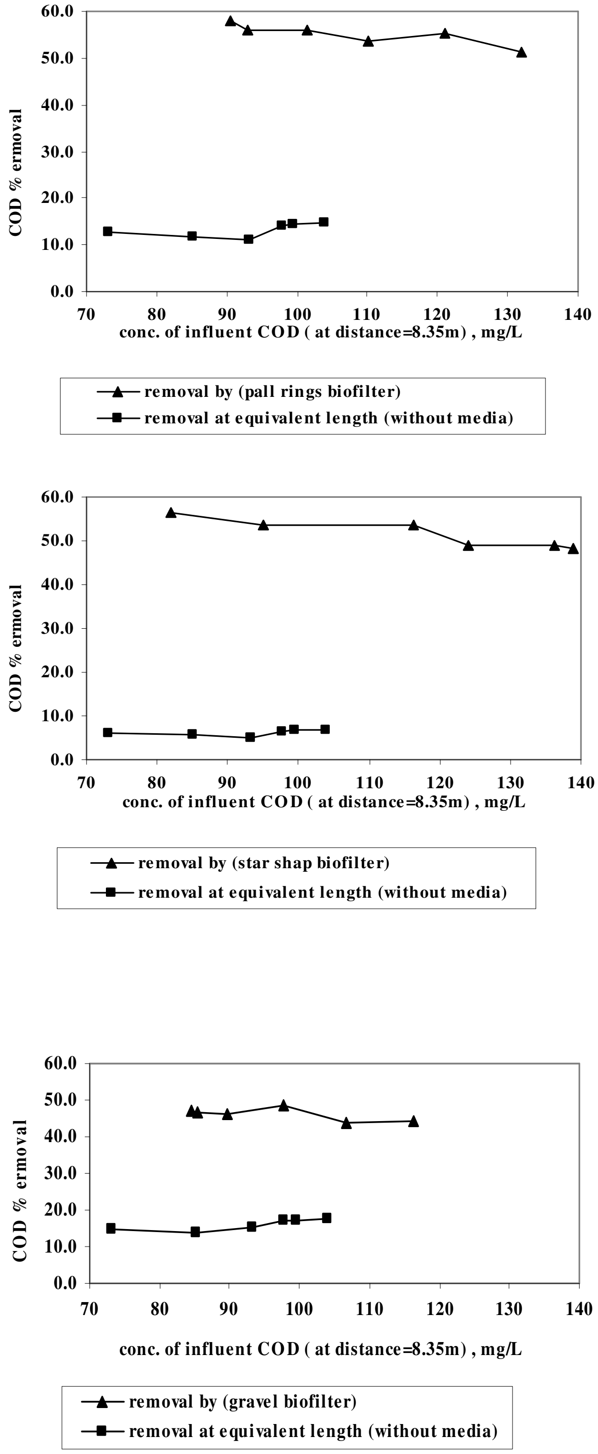


Fig. 6. Removal efficiency of COD by three biofliter compared to "No Media" (4th run - Q= 3.15 L/s)

During the whole study it was observed that the percentage of increase of water level upstream *the star shape* biofilter was greater than that of *the pall rings* biofilter, which indicate that the portion of water passing through *the pall rings* filter is more than that passing through *the stare shape* filter. This shows that more water was exposed to treatment by the attached microorganisms in the pall rings biofilter; hence the COD removal ratio by pall rings biofilter was greater than that of the star shape biofilter.

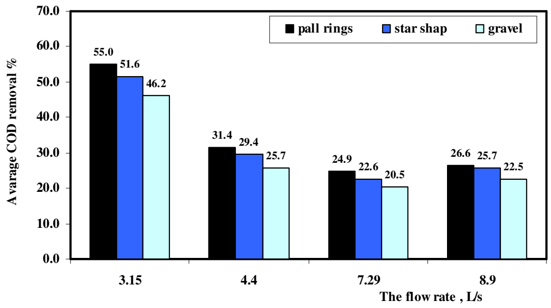


Figure 7: Comparison between three biofilters in COD removal efficiency during the whole study

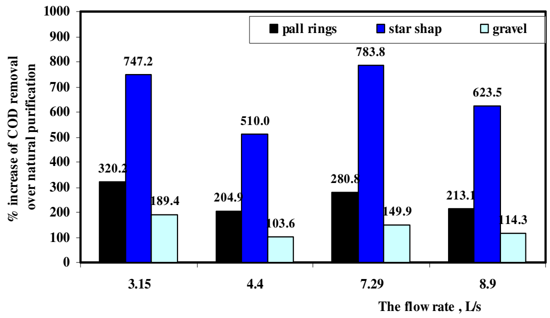


Figure 8: The effect of biofilters on increasing the stream self-purification capacity

Figure 8 shows the percentage of increase of COD removal rates achieved by the three biofilters over natural purification at the same equivalent lengths of the channel without media. The highest % of increase was achieved by the star shape biofilter and ranged between 510% and 783.8%. This could be attributed to its smallest length in the flow direction (10.0 m), which allows slight treatment in the reference stream at an equivalent length to the biofilter. The % of increase achieved by pall rings biofilter ranged between 204.9% and 320.2%, whereas the lowest % of increase was achieved by gravel biofilter, and ranged between 103.6% and 189.4% attributed to its longest length in the flow direction (26.0 m), which allowed for more treatment in the reference stream at an equivalent length compared to the other two biofilters.

CONCLUSIONS

Based on the experimental program executed in this research, and limited to both the tested materials and the testing procedures employed, the following conclusions have been reached:

- The use of submerged biofilters in polluted streams increases the stream self-purification capacity at the discharging point.
- The performance of submerged biofilters is affected by total hydraulic loading (THL). As the (THL) increases the COD removal ratio decreases.
- At the smallest flow rates the variation of organic volumetric loading rate (VLR) has a slight effect on the performance of biofilters.
- Pall rings media biofilter achieved the highest COD removal ratio compared to the star shape and gravel biofilters while having the same total surface area provided for biofilm growth.
- Star shape media biofilter achieved the highest % increase of water level in upstream compared to the pall rings and gravel biofilters.
- Star shape media biofilter achieved the highest % increase of COD removal ratio over natural purification at an equivalent length of the channel without media compared to pall rings and gravel biofilters.

- The characteristics of the used media; such as specific area, void ratio, and configuration has a great effect on biofilter performance, and heading up of water level upstream the biofilter.

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