EFFECT OF ORGANIC LOADING RATE AND TEMPERATURE ON THE PERFORMANCE OF HORIZONTAL BIOFILTERS

D. S. El Monayeri, N. N. Atta, S. El Mokadem and A. M. Aboul-fotoh

Environmental Engineering Department, Zagazig University, Egypt

ABSTRACT

Three horizontal biofilters had been constructed to investigate the effect of temperature and organic loading rate on the performance of them the filters were packed with two different plastic media -pall rings, star shape- and gravel. The used biofilters experimented under different organic loading rates: for BOD loading from 9 (Kg BOD /m^3/d) to 32 (Kg BOD /m^3/d); and for COD loading from 14 (Kg COD /m^3/d) to 75 (Kg COD /m^3/d) and temperatures from 15 to 31 °C, the removal ratios (RR) for BOD and COD were determined. As the organic loading rate increased the BOD and COD removal ratio increased for the three used biofilters and the two used plastic media had a higher BOD and COD removal ratios than gravel under the same organic loading rate. Also the increase in temperature increased the COD and BOD removal ratios for the three used biofilters.

Keywords: BOD, COD, horizontal biofilter, and organic loading rate.

INTRODUCTION

There are many variables affecting the performance and design of horizontal biofilters, some of these variables had been studied and, in some cases, definite trends had been established. In other cases difficulties in controlling interdependent variables not under study have made it possible to draw definite conclusions concerning performance (Abdel-rahman 2002) these factors are media length, temperature, media type and organic loading rate. Waste water temperature has an effect on both sedimentation and biological treatment processes, temperature influence on the rate at which biological oxidation occurs (Adin et al 1984). In the submerged bioreactors the removal of organic matters is performed by a microbial film on the surface of the filter media, it has been known that the amount of film accumulating in the filter fluctuates seasonally and the amount of film increased in winter and decreased in summer (Honda and Matsumoto 1983).

Muslu (1983) in his study on the performance of trickling filters stated that "The BOD removal through the depth of the filter followed apparent first order kinetics at all flow rates used in this study" so the BOD removal ratio can be discussed using the following equation:

$$L_e = L_o * e^{-\beta * H} \tag{1}$$

where:

L_o = Influent BOD_5 (mg/L).
L_e = Effluent BOD_5 (mg/L).
H = Bioreactor length (m).
β = Factor depends on the used media properties, the discharge and K_T (m^{-1})
K_T = an experimentally determined rate constant at any temperature T °C, and according to Howland (Gotaas (1973)) and Stein et al. 2006).

$$K_T = K_{20} \times (\theta)^{T-20}$$

K_{20} = Rate constant at temperature 20 °C.
θ = A dimensionless temperature coefficient.

Sarti et al (2004) proposed a mathematical model for the relation between COD removal and bioreactor length using the following equation:

$$1 - E_{COD} = e^{-\omega * H} \tag{2}$$

where:

E_{COD} = COD removal efficiency,
H = Bioreactor length (m),
ω = Factor depends on the used media properties, the discharge and K_c (m^{-1}),
K_c = an experimentally determined rate constant at any temperature T °C like K_T.

The organic removal rate depends mainly on temperature, the relationship between the organics removal efficiency E_T for temperature T °C and BOD removal efficiency E_{20} for temperature 20 had been expressed by the following two relationships:

1- (Onda et al., 1968):

$$E_T = E_{20} \times (\theta)^{T-20} \tag{3}$$

2- (Christoulas, et al., 1990):

$$\frac{1}{E_{20}} - 1 = \left(\frac{1}{E_T} - 1\right) \times (\theta)^{T-20} \tag{4}$$

For the two relations the range of θ varied from 1.015 to 1.045. Pierce also concluded that; relatively low wastewater temperatures during winter generally reduced the overall plant removal of BOD by about 1/3.

The organic loading rate had an effect on the performance of horizontal biofilters such that the effluent organic concentration increases markedly as flow rate is increased, at higher feed rates concentration still increases more slowly, approaching feed concentration at infinite feed rate. The explanation for these results is that, substrate utilization is mass transfer limited because substrate in the liquid layer immediately adjacent to the slime layer is depleted rapidly. The concentration gradient penetration depth and the HLR are in reverse proportional (Maier, et. al., 1967).

Rittmann (1984) stated that "Time varying input loading, in comparison with steady input loading, causes an increase in average effluent concentration". Experimental results indicated that the percentage removal increases at increased BOD load. Also the organic loading rate has an effect on the biofilm growth rate Wijeyekoon et al (2004) demonstrated that biofilm internal microstructure is affected by substrate loading rate with increasingly high substrate concentrations producing increasingly compact biofilm with lower porosity.

MATERIALS AND METHODS

Experimental Equipment:

The experimental model consists of four channels Fig (1) the first channel was free from media and didn't used in this research, each channel of the remaining three channels were act as a horizontal biofilter with different placed media such that gravel was placed in the 2nd channel, Star shape media was placed in the 3rd channel and the pall rings media was placed in the 4th channel. Table (1) shows the properties of the used three media-. The model was placed on the perm of Belbies drain at KM 35.00. The four channels each of width 40 cm and the water depth through the study will remain constant at 25 cm. The inlet discharge to the four channels was controlled to be equal by using a rectangular weir of 20 cm width for each channel the discharge passing to each channel was determined by measuring the head of the water above the weir which had been calibrated in the laboratory at Zagazig University.

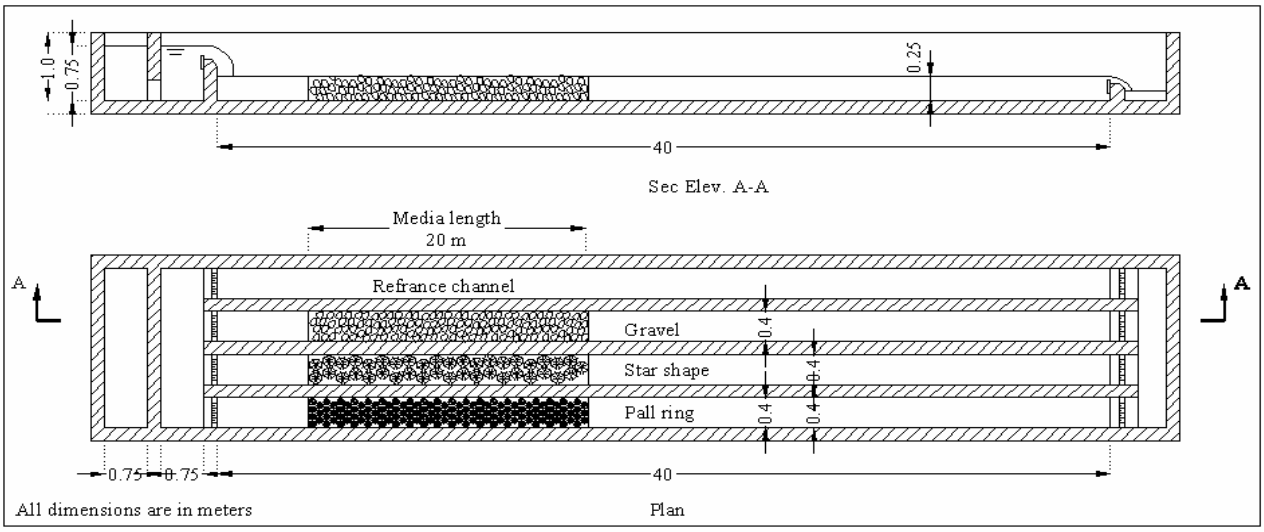

Figure (1) the used model lay out

Table (1) the used media properties

Media type	Gravel	Star shape	Pall rings
Material	Gravel	PVC	PVC
Surface texture	Open pored	Smooth	Smooth
Outer diameter (cm)	3.50	6.40	5.00
Height (cm)	-----	From 0.50 to 2.4	5.00
Porosity (%)	43	82	83
Specific surface area (m^3/m^2)	57.50	152.15	71.24
Used media total volume (m^3)	2	2	2

Photo (1) the three used media (Star shape, pall rings and gravel) respectively

Experimental Procedures:

The BOD, COD, Solids, Temperature, pH and dissolved oxygen were measured from to samples locations just before and just after the media. All the measurements were analyzed in Environmental Engineering Department Laboratory, Faculty of Engineering, Zagazig University, Egypt, in accordance with "The Standard Methods for the Examination of Water and Wastewater", 20th Edition, 2000". The properties of the inlet wastewater for the four channels during the study were as follow in table (2).

Table (2) the inlet wastewater properties

Parameters	Rang	Average value
pH	7.1 – 7.9	7.5
Temperature (°C)	15-31	23
COD (ppm)	75 – 151	113
BOD (ppm)	42 – 112	77
Total solids (ppm)	650 - 1520	1085
Dissolved solids (ppm)	410 – 1108	759

In order to investigate the effect of temperature on the organic degradation process the organics removal ratios were calculated for two different discharges 5 (Lit/s) and 7

(Lit/s) at a known temperature, then at another temperature the organics removal ratios were recalculated for the same two discharges 5 (Lit/s) and 7 (Lit/s). Also in order to investigate the effect of organic loading rate on the organic degradation process the discharge for each channel was changed from 3 (Lit/s) to 11 (Lit/s) with step 2 (Lit/s) with determining the inlet COD and BOD concentrations and samples from just before the media and just after the three media were taken and from the corresponding reference channel at the same distances.

RESULTS

Effect of temperature on the biological degradation process

Sabbah et al (2004) studied the performance of UASB and stated that "The results show COD removal efficiencies of about 60% in summer (20°C – 27°C), and lower COD removals of between 20% and 40% during winter (12°C – 14°C)". As the temperature increased the BOD removal ratio will increased (Abdel-rahman 2002). So in order to investigate the effect of temperature on the BOD and COD removal ratios; the value of θ must be determined. In order to do that the removal ratio was determined for each channel at two different temperatures and also at two different flow rates. As mentioned before the effect of temperature on filter efficiency has been expressed by two relationships (Onda et al., 1968) and (Christoulas, et. al., 1990) for the two relations the range of θ varied from 1.015 to 1.045. But Metcalf and Eddy (1991) show the following table (3) for the value of θ for different biological processes.

Table (3) the values of θ for different biological processes

Process	**Value of θ**	
	Range	**Typical**
Activated sludge	1.00-1.04	1.02
Aerated lagoons	1.06-1.12	1.09
Trickling filters	1.02-1.14	1.08

By knowing the efficiency at any two temperatures the factor θ can be calculated using the above equations and then the average value would be used, table (4) calculate θ using the first relation, table (5) used the second relation and table (6) give the average value of θ. Also, for the COD removal efficiency, table (7) calculates θ using the first relation, table (8) used the second relation and table (9) gives the average value of θ.

Table (4) the values of θ using Onda formula

Channel	Q = 5 (l/s)		θ	Q = 7 (l/s)		θ	θ ave
	T=15 °C	T=25 °C		T=18 °C	T=26 °C		
gravel	19.15	27.72	1.038	18.20	26.21	1.047	1.042
star shape	22.20	40.90	1.063	20.78	35.79	1.070	1.067
pall rings	20.10	35.07	1.057	20.10	31.19	1.056	1.057

Table (5) the values of θ using Christoulas formula

Channel	Q = 5 (l/s)		θ	Q = 7 (l/s)		θ	θ ave
	T=15 °C	T=25 °C		T=18 °C	T=26 °C		
gravel	19.15	27.72	1.049	18.20	26.21	1.060	1.055
star shape	22.20	40.90	1.093	20.78	35.79	1.099	1.096
pall rings	20.10	35.07	1.079	20.10	31.19	1.076	1.078

Table (6) the average values of θ

Channel	θ Onda	θ Christoulas	θ ave
gravel	1.042	1.055	1.0485
star shape	1.067	1.096	1.0812
pall rings	1.057	1.078	1.0674

Table (7) the values of θ using Onda formula for COD removal

Channel	Q = 5 (l/s)		θ	Q = 7 (l/s)		θ	θ_{ave}
	T=15 °C	T=25 °C		T=18 °C	T=26 °C		
gravel	25.15	41.73	1.052	28.60	38.71	1.039	1.045
star shape	26.18	56.12	1.079	33.85	53.72	1.059	1.069
pall rings	34.75	61.33	1.058	37.50	56.51	1.053	1.056

Table (8) the values of θ using Christoulas formula for COD removal

Channel	Q = 5 (l/s)		θ	Q = 7 (l/s)		θ	θ_{ave}
	T=15 °C	T=25 °C		T=18 °C	T=26 °C		
gravel	25.15	41.73	1.079	28.60	38.71	1.059	1.069
star shape	26.18	56.12	1.137	33.85	53.72	1.108	1.122
pall rings	34.75	61.33	1.115	37.50	56.51	1.101	1.108

Table (9) the average values of θ for COD removal

Channel	θ_{Onda}	$\theta_{Christoulas}$	θ_{ave}
gravel	1.045	1.069	1.0569
star shape	1.069	1.122	1.0958
pall rings	1.056	1.108	1.0819

Based on previous research the relations for β and ω –taking the effect of temperature- can be summarized in tables (10) and (11).

Table (10) the relation between β and Ac/Q and temperature for the three used media

Media	The equation	
	For $A_c/Q \le 14.29$ (s/m)	For $A_c/Q > 14.29$ (s/m)
Gravel	$\beta_G = \frac{0.00075*(1.049)^{T-20}*A_c}{Q}$	$\beta_G = \frac{0.0006*(1.049)^{T-20}*A_c}{Q}$
Star shape	$\beta_S = \frac{0.0009*(1.081)^{T-20}*A_c}{Q}$	$\beta_S = \frac{0.0008*(1.081)^{T-20}*A_c}{Q}$
Pall rings	$\beta_P = \frac{0.0008*(1.067)^{T-20}*A_c}{Q}$	$\beta_P = \frac{0.0007*(1.067)^{T-20}*A_c}{Q}$

Table (11) the relation between ω and Ac/Q and temperature for the three used media

Media	The equation	
	For $A_c/Q \le 14.29$ (m/s)	For $A_c/Q > 14.29$ (m/s)
Gravel	$\omega_G = \frac{0.0012*(1.057)^{T-20}*A_c}{Q}$	$\omega_G = \frac{0.001*(1.057)^{T-20}*A_c}{Q}$
Star shape	$\omega_S = \frac{0.0017*(1.096)^{T-20}*A_c}{Q}$	$\omega_S = \frac{0.0012*(1.096)^{T-20}*A_c}{Q}$
Pall rings	$\omega_P = \frac{0.0019*(1.082)^{T-20}*A_c}{Q}$	$\omega_P = \frac{0.0015*(1.082)^{T-20}*A_c}{Q}$

Effect of BOD loading rate on the BOD removal ratio

Figures (2, 3, and 4) show the relation between BOD loading rate and BOD removal ratios for each channel. As the BOD loading increased the BOD removal ratio for the four channels decreased. This trend agreed with Richards and Reinhart (1986) who studied the effect of BOD loading on two filters with depths 3 m and 6.1 m and found that for the 3 m depth filter when the BOD loading decreased from 0.60 (Kg/m^3.d) to 0.40 (Kg/m^3.d) the BOD removal increased from 67% to 78%; while for the 6.1 m depth filter when the BOD loading decreased from 0.80 (Kg/m^3.d) to 0.40 (Kg/m^3.d) the BOD removal increased from 73% to 85%. Lei Yang et al. (2001) studied the effect of BOD loading rate on the performance of three different filters -for the treatment of aquaculture water- one of these filters was a horizontal flow submerged biofilter packed with plastic media and found that as the BOD loading rate increased from 20 (g/m^3.d) to 40 (g/m^3.d) the BOD removal ratio decreased from 65% to 55%.

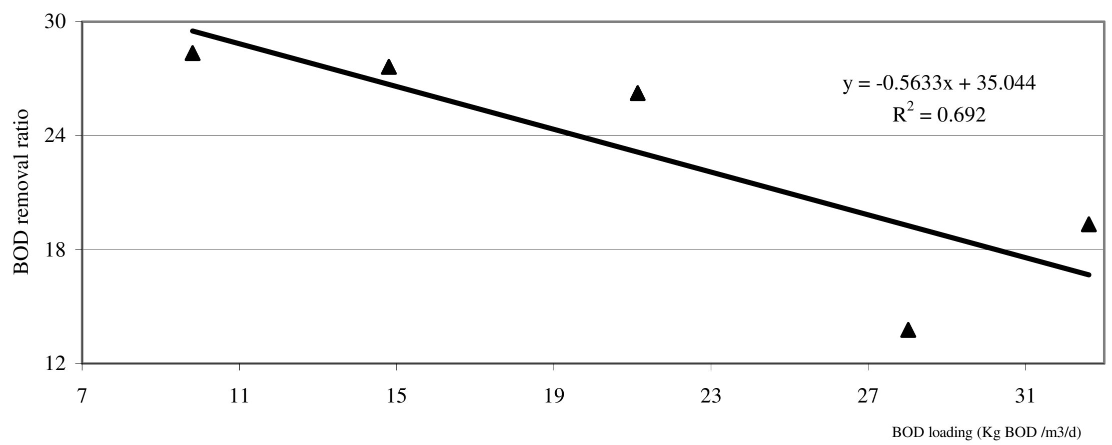

Fig (2) Relation between BOD loading and BOD removal ratio for gravel media channel

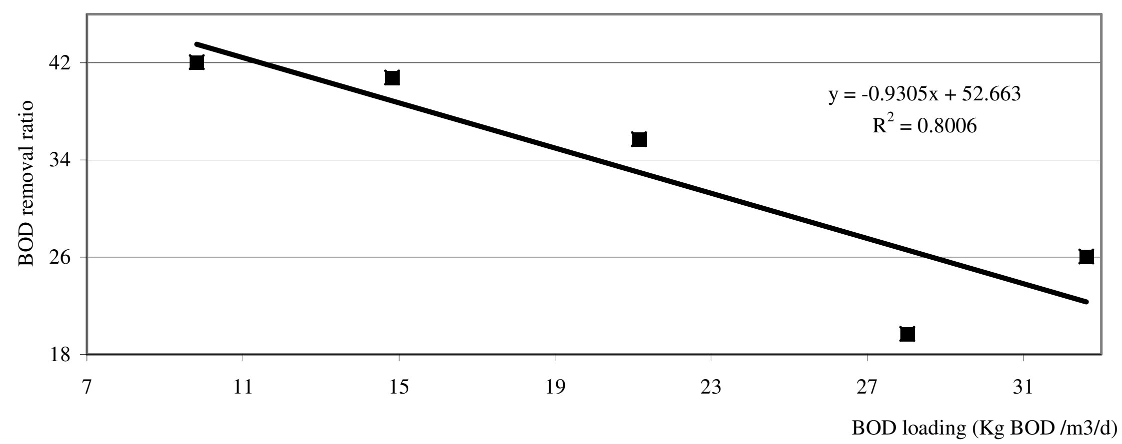

Fig (3) Relation between BOD loading and BOD removal ratio for star shape media channel

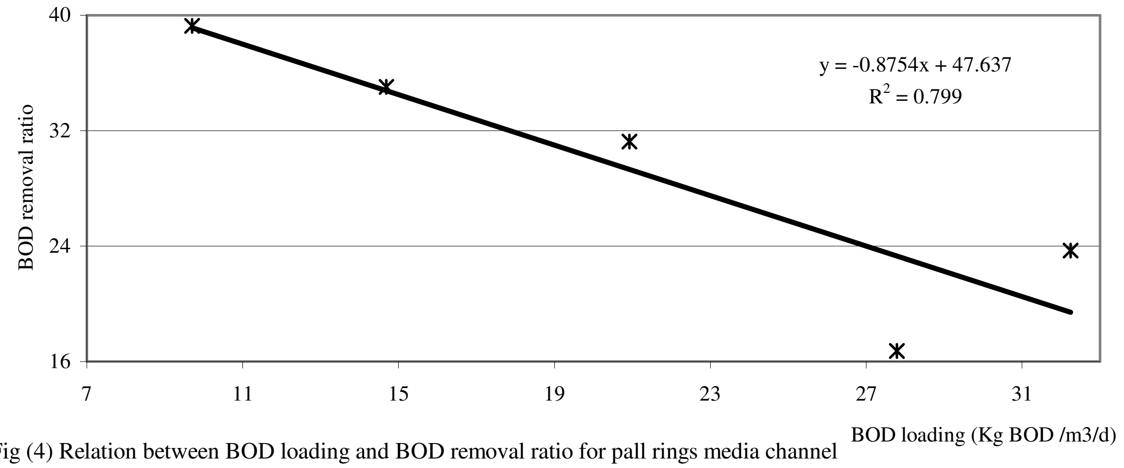

Fig (4) Relation between BOD loading and BOD removal ratio for pall rings media channel

Effect of COD loading rate on the COD removal ratio

Figures (5, 6, and 7) show the relation between COD loading rate and COD removal ratios for each channel. As the COD loading increased the COD removal ratio for the four channels decreased. This trend agreed with Kuan-Yeow Show and Joo-How Tay (1999) in their study on the performance of an aerobic filter using three filters found that when the COD loading rate decreased the COD removal ratio of each filter increased table (12) shows the COD removal ratios for the three filters against the COD loading rate.

Mann et al. (1999) in his study for the impact of using of sunken media and floating media on the performance of biological aerated filters found that the COD removal ratio of the sunken media filter decreased from 68.3% to 30% when the COD loading rate increased from 0.568 (Kg/m^3.d) to 1.403 (Kg/m^3.d) and the COD of the floating media filter also decreased from 75.3% to 40% under the same COD loading rates.

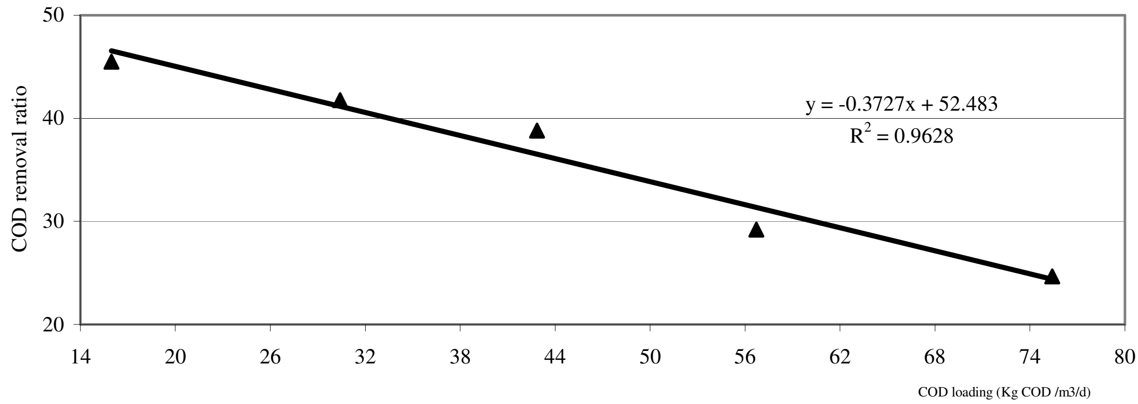

Fig (5) Relation between COD loading and COD removal ratio for gravel media channel

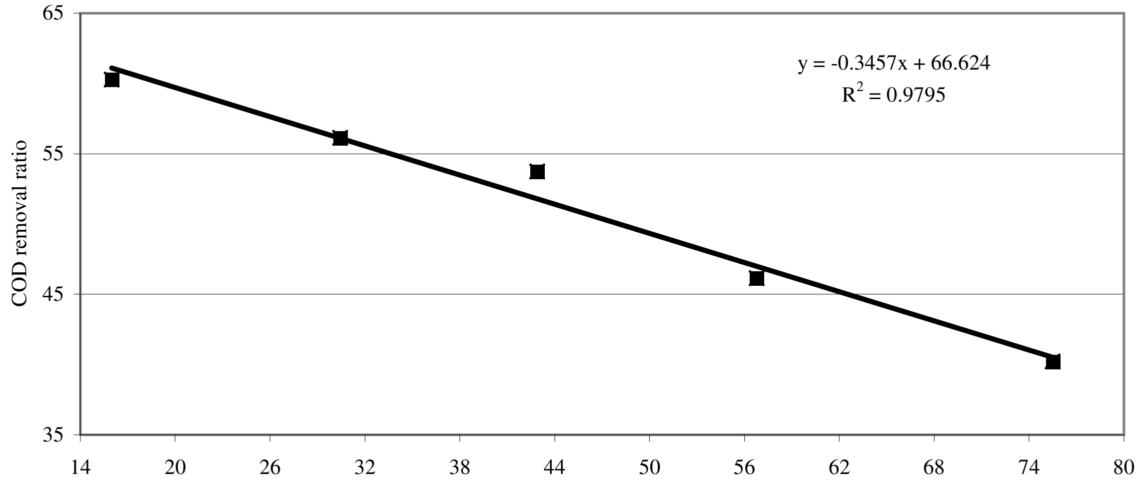

Fig (6) Relation between COD loading and COD removal ratio for star shape media channel

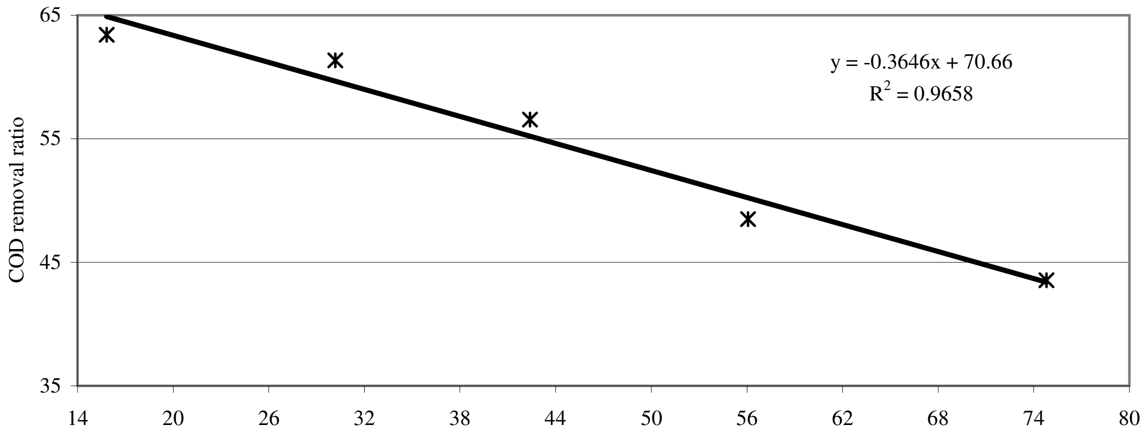

Fig (7) Relation between COD loading and COD removal ratio for pall rings media channel

Table (12) COD removal results from Kuan-Yeow Show and Joo-How Tay

COD loading g/l/d	FILTER ONE	FILTER TWO	FILTER THREE
	COD removal ratio %	COD removal ratio %	COD removal ratio %
2	97	95	95
4	94	94	92
8	92	90	75
12	77	75	67
16	73	70	55

CONCLUSIONS

From the above results the following conclusions could be deduced:

1- As the temperature increased the biodegradation processes in the pilot increased, which mean that the efficiency of the horizontal biofilters in summer will be greater than the efficiency in winter.

2- Temperature has a higher effect on the plastic media than its effect on gravel this is may be because of the higher porosity percent which mean that greater amount of water will be passed through the biofilter media.

3- As the organic loading rate increased the efficiency of the three biofilters decreased this is manly because of the decrease in retention time and the different in biofilm internal microstructure.

4- The used two plastic media are more effective in the treatment process than gravel under the same organic loading rate this is because they have a higher specific surface area with higher porosity.

REFERENCES

1. Abdel-rahman W.H. "Discharge of Domestic Waste Water into Rivers". Ph.D. thesis, Faculty of Engineering, Helwan University, Cairo, Egypt, 2002.
2. Adin A., Baumann E.R., Warner F.D. "Evaluation of temperature effects on trickling filter plant performance". Water Science and Technology, Vol. 17, pp. 53-67, 1984.
3. Christoulas D.G., Liakos S.N., Andreadakis A.D. "Performance Relationship for Low and Intermediate Rate Biological Filters". Water Research Vol. 24, No. 5, PP607-614, 1990.
4. Gotaas H.B., Asce F., Galler W.S. and Asce M. "Design optimization of biological filters models". Journal of Environmental Engineering Division, Vol. 99, No. EE6, pp. 831-849, 1973.

5. Honda Y. and Matsumoto J. "The effect of temperature on the growth of microbial film in model trickling filter". Water Research, Vol. 17, No. 4, pp. 375-382, 1983.
6. Kuan Yeow Show and Joo Hwa Tay "Influence of support media on biomass growth and retention in anaerobic filters" Journal of Water Research, Vol. 33, No. 6, pp. 1471-1481, 1999.
7. Maier W.J., Behn V.C., Gates C.D. "Simulation of the Trickling Filter Process". Journal of the Sanitary Engineering Division, Vol.93, No.SA4, PP91-112, 1967.
8. Mann A.T., Mendoza-Espinosa L. and Stephenson T. "Performance of floating and sunken media biological aerated filters under unsteady state conditions". Water Research Vol.33, No.4, PP. 1108-1113, 1999.
9. Metcalf & Eddy, Inc. Wastewater Engineering: Treatment, Disposal and Reuse. 3rd Edition. New York: McGraw-Hill, 1991.
10. Muslu Y. "Distribution of Retention Times in Model Biological Filters Containing Packed Spheres". Water Research, Vol.20, No.3, PP259-265, 1986.
11. Pierce D.M. "Upgrading Trickling Filters". MCD-42, Report reviewed by the Environmental Protection Agency, Virginia, 22151.
12. Richards T., Reinhart D. "Evaluation of Plastic Media in Trickling Filters". Journal of Water Pollution Control Federation Vol.58, No.7, PP774-783, 1986.
13. Rittmann B. E. "The effect of load fluctuations on the effluent concentrations produced by fixed film reactors". Water Science and Technology, Vol. 17, pp. 45-52, 1984.
14. Sabbah1 I., B. Ghattas, A. Saliba-Hayeek, N. Massalha, A. El-Rabi, A. El-Araby, E. Wasef, H.
15. Sarti A., Zaiat M. and Foresti, "Evaluation of a mechanistic mathematical model of a packed bed anaerobic reactor treating domestic wastewater" Latin American Applied Research, Vol. 34, pp. 127-132, 2004.
16. Mehawed, S. Admaon, O. Lahav, S. Tarre, N. Shaul, M., Beliavski, and M. Green "Appropriate Technologies for wastewater Treatment and Reuse in the Rural Areas of the Middle East - Case Study of Successful Regional Cooperation". Report for USAID (MERC program) PCE-G-00-98-00011-00.
17. Stein O.R., Biederman J.A., Hook P.B., Allen W.C. "Plant species and temperature effects on the k–C* first-order model for COD removal in batch-loaded SSF wetlands". Ecological Engineering 26, pp. 100-112, 2006.
18. WEF - Water Environment Federation and American Society of Civil Engineers - "Design of municipal wastewater treatment plants". CD-product, 1998.
19. Wijeyekoon S., Mino T., Satoh H. and Matsuo T. "Effects of substrate loading rate on biofilm structure", Water Research, Vol. 38, pp. 2479-2488, 2004.