J. Agric. Sci. Mansoura Univ., 29 (12): 7625 - 7640, 2004

PERFORMANCE CHARACTERISTICS OF A PILOT PLANT OF GRAVEL BED HYDROPONIC SYSTEM (GBH)

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ABSTRACT

Artificial wetlands are low cost-technology wastewater treatment system and could be introduced as secondary or tertiary step in the treatment system. To study the performance characteristics of these systems, Two Gravel Bed Hydroponic pilot-scale systems (GBH) were made of iron sheets (4mm thickness) with dimension of 4m long, 30cm width and 40cm high, provided with three tapes for controlling inlet flow, effluent drain and system sewage depth (SD). Both units were lined with bitumen; filled with gravel aggregates, cultivated with papyrus rhizomes and irrigated for two month with tap water for plant growth and system establishment. The SD of the first and the second systems were designed to operate at 10 and 20 cm sewage depth (SD), respectively. After this period, both GBH models were fed with primary treated wastewater from Zenien wastewater treatment plant in a batch mode. Removal efficiencies of SS, COD, BOD, nitrogen forms and indicator microorganisms under different retention times of 4, 8, 12, 16 and 24 hrs were studied. Results were deeply discussed.

Keywords: Hydroponic system (GBH), destruction pathogenic bacteria, coliform bacteria, Biochemical oxygen demand (BOD), chemical oxygen demand (COD)

INTRODUCTION

Artificial wetlands are alternative technology wastewater treatment system that mimics the biogeochemical processes inherent in natural wetlands. The use of constructed wetlands for wastewater treatment is not a new idea. Ancient Egyptian cultures and Chinese made use of their pollution abatement potential (Brix, 1994). Natural physical, chemical, and biological processes that occur in the soil-water-plant ecosystem dictate treatment of wastewater in natural and artificial wetland systems. Wetland systems are capable of removing almost all of the major and minor constituents of wastewater pollutants such as suspended solids, organic matter, nitrogen, phosphorus, trace elements, trace organic compounds, and microorganisms to degree could be comparable with the secondary permissible guidelines. Wetlands, when compared to mechanical treatment systems, require more land area and yet provide more diverse microenvironments using less mechanical and human labor (Hammer, *et al.,* 1993). The emerged plants cultivated in the artificial wetlands tend to have a higher potential in wastewater treatment because they can serve as a microbial habitat and as a filtering medium, and they are able to grow in a wide variety of wastewater (Reed *et. al.*, 1992). They are able to transfer oxygen from atmosphere to the roots and rhizomes to set up an aerobic environment in the rhizosphere (Armstrong *et. al.*, 1990).

This work is conducted to study the performance characteristics of the Gravel Bed Hydroponic system for removing suspended solids (SS), chemical oxygen demand (COD), Biological Oxygen Demand (BOD) and nitrogen forms (ammonia, nitrate and total nitrogen). System efficiency in the destruction of bacteria pathogenic indicators was also determined through assaying the numbers of both total and fecal coliform bacteria.

MATERIALS AND METHODS

Two Gravel Bed Hydroponic pilot-scale systems (GBH) were made of iron sheets (4mm thickness) with dimension of 4m long, 30cm width and 40cm high, provided with three tapes for controlling inlet flow, effluent drain and system sewage depth (SD). The SD of the first and the second systems were designed to operate at 10 and 20 cm sewage depth (SD), respectively. Both systems were lined with bitumen, filled with gravel aggregates (10-20cm in diameter); cultivated with papyrus rhizomes and irrigated for two month with tap water for plant growth and system establishment. After this period, each of them was fed with 22L (first model) and 44L (Second model) of primary treated wastewater from Zenien wastewater treatment plant in a batch mode. Both systems were operated at retention times of 4, 8, 12, 16 and 24 hrs, each for 30 days. At last 15 days of each retention time operation regime, samples of wastewater influent and effluents drained from both GBH systems were taken daily for determination of pH, suspended solids, chemical and biochemical oxygen demand and nitrogen forms (ammonia, nitrate and total nitrogen). Pathogenic indicator bacteria were also determined. The previous parameters were determined using the methods recommended by APHA, AWWA and WEF (1998).

RESULTS AND DISCUSSION

1. Hydrogen ion concentration (pH):

The pH values of the wastewater influent ranged between 7.0 and 7.4 (Table 1). The effluents drained from both GBH models exhibited little changes in their pH values. The effluents drained from first GBH (10cm SD) model operated at retention times of 4, 8, 12, 16 and 24 hrs showed pH values ranged from 6.8 to 7.7, 6.9 to 7.3, 7.3 to 7.5, 7.2 to 7.5 and 7.3 to 7.5, respectively. While the 20 cm SD GBH model produced effluent with pH values ranged from 6.7 to 7.5, 6.9 to 7.4, 7.1 to 7.5, 7.0 to 7.2 and 6.8 to 7.4 when operated at retention times of 4, 8, 12, 16 and 24 hrs, respectively.

In aquatic system plant and algal photosynthetic processes peak during the daytime hours, creating a diurnal cycle in pH. Photosynthesis utilizes CO_2 and produces oxygen, thereby shifting carbonate–bicarbonate–carbon dioxide equilibra to higher pH.

Table (1): Minimum and maximum hydrogen ion concentrations (pH) of wastewater influent and effluents drained from the gravel bed hydroponic (GBH) system operated under different conditions of sewage depth and retention time.

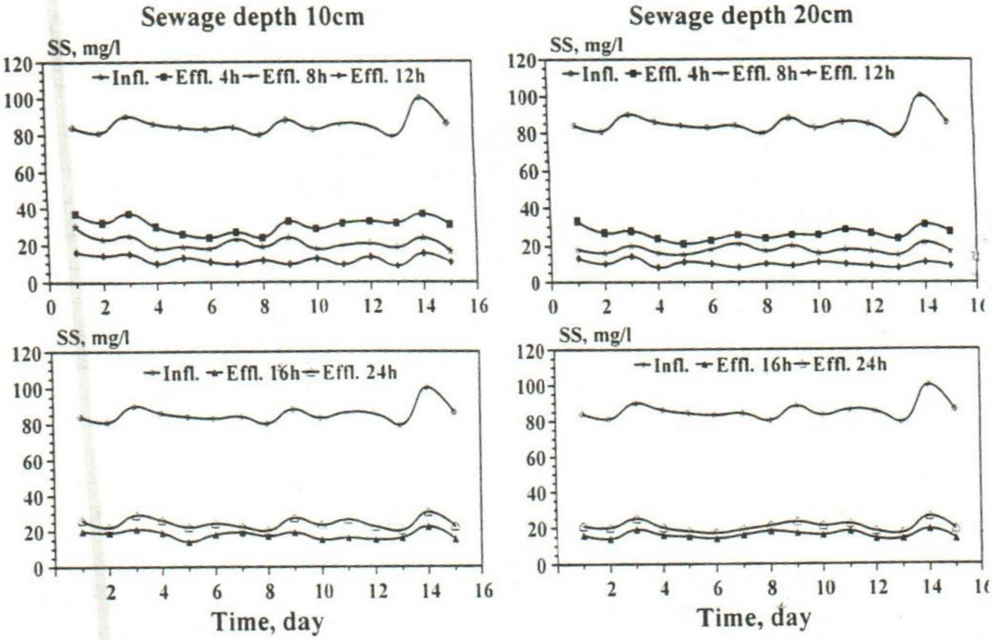
Retention time (RT)	Hydrogen ion concentration			
	GBH sewage depth			
	10cm		20cm	
	Min.	Max.	Min.	Max.
	Influent			
	7.0	7.4	7.0	7.4
	Effluents			
4 hrs	6.8	7.7	6.7	7.5
8 hrs	6.9	7.3	6.9	7.4
12 hrs	7.3	7.5	7.1	7.5
16 hrs	7.2	7.5	7.0	7.2
24 hrs	7.3	7.5	6.8	7.4

2. Total Suspended Solids (SS):

Total suspended solids of influent wastewater ranged between 79 and 100 mg/L with an average of 85.3 (±4.8) mg/L while the effluents drained from both GBH models exhibited different reductions and their TSS values were greatly affected by the RTs (Fig.1 and Table. 2). The GBH model of 10cm SD produced effluents with TSS concentrations averages of 30.9 (±4.2), 21.2 (±3.5), 12.3(±2.3), 17.7 (±2.4) and 24.1(±3.0) mg/L while the removal percentages of TSS were 63.8, 75.2, 85.6, 79.3 and 71.8 % when the model was operated at RT of 4, 8, 12, 16 and 24 hrs, respectively.

The effluents drained from the GBH model of 20cm SD showed lower average values of TSS. These averages were 26.5(±3.1), 17.7(±2.1), 10.1(±1.7), 16.0 (±1.8) and 28.5 (±2.6) mg/L when this model was operated at RTs of 4, 8, 12, 16 and 24 hrs, respectively. The removal percentages of TSS were higher than those of the model of 10cm SD. They were 68.9, 79.3, 88.2, 81.2 and 66.6 %, respectively. From the previous results it could be clearly confirmed that the best removal efficiencies of TSS were obtained when both GBH models were operated at RT of 12 hrs.

Settleable organics are rapidly removed in wetland systems by quiescent conditions, deposition and filtration. Many investigators found that the natural and artificial wetlands effectively removed suspended solid by sedimentation, filtration and biochemical oxidation of organic matter by microorganisms. The obtained results are in agreement with those reported by Watson *et al.* (1987), Bahgat (1992), Kadlec & Rebert (1996) and Davison *et al.*, (2001). They reported that removal efficiency of total suspended solids by constructed wetland ranged from 52 to 96%.


Sewage depth 10cm

Sewage depth 20cm

Fig. (1): Changes in the concentration of total suspended solids (SS) for influent and effluents drained from both gravel bed hydroponic (GBH) models operated under different conditions of retention times (4, 8,12, 16 and 24hrs) and sewage depths (10 and 20cm).

Table (2): Removal efficiencies, maximum, and minimum concentrations of SS (mg/L) for wastewater influent and effluent drained from both GBH models

System Retention time (RT)	Suspended solids, mg/L							
	GBH sewage depth							
	10cm				20cm			
	Min.	Max.	Avg. (±Sd)	Rem. %	Min.	Max.	Avg.(±Sd)	Rem. %
	Influent							
	79	100	85.3 (4.8)	—	79	100	85.3 (4.8)	—
	Effluents							
4 hrs	24	37	30.9 (4.2)	63.8	21	33	26.5 (3.1)	68.9
8 hrs	17	30	21.2 (3.5)	75.2	15	22	17.7 (2.1)	79.3
12 hrs	9	16	12.3 (2.3)	85.6	8	14	10.1 (1.7)	88.2
16 hrs	14	22	17.7 (±2.4)	79.3	14	19	16.0 (±1.8)	81.2
24 hrs	20	30	24.1 (±3.0)	71.8	17	26	28.5 (±2.6)	66.6

3. Chemical (COD) and biochemical (BOD) Oxygen Demands:

Values of COD for influent wastewater ranged between 184 and 228 mg/L with an average of 202 (±11.9) mg/L. Concentration of BOD_5 for influent wastewater ranged between 127 and 169 mg/L with an average of 146 (±10.4) mg/L. The effluents drained from both GBH models exhibited different reductions and their COD (Fig.2 and Table3) and BOD_5 (Fig.3 and Table 4) values were greatly affected by the operated retention time and sewage depth.

The GBH model of 10 cm SD produced effluents with COD average values of 54.2 (±5.5), 44.3 (±4.2), 36.2 (±3.1), 41.0 (±3.4) and 48.9 (±5.1) mg/L, when this GBH model was operated at RT of 4, 8, 12, 16 and 24 hrs, respectively. The corresponding figures for COD removal percentages were 73.3, 78.2, 82.2, 79.8 and 75.9 %, respectively. The BOD_5 average values were 34.9 (±4.3), 27.3 (±3.6), 19.6 (±3.6), 25.3 (±3.7) and 31.1 (±5.0) mg/L, when the model was operated at RT of 4, 8, 12, 16 and 24 hrs, respectively. The BOD_5 removal percentages were 76.1, 81.3, 86.6, 82.7, and 78.7 %, respectively.

The effluents drained from the GBH model of 20cm SD showed lower COD and BOD_5 values. The COD averages were 50.1 (±4.3), 39.2 (±2.9), 31.2.1 (±2.5), 34.9 (±3.8) and 44.5 (±5.2) mg/L while the removal percentages of COD were 75.3, 80.7, 84.6, 82.8 and 78.1 % when the model was operated at RT of 4, 8, 12, 16 and 24 hrs, respectively. The average BOD_5 values were 31.5 (±5.2), 24.3 (±4.6), 15.8 (±3.1), 20.9 (±3.9) and 27.0 (±5.3) mg/L, when this GBH model was operated at RT of 4, 8, 12, 16 and 24 hrs, respectively. The BOD_5 removal percentages were 78.7, 83.4, 89.2, 85.7 and 81.52 % respectively. it was clear to confirm that the best removal efficiencies of COD and BOD_5 were obtained when both GBH models were operated at RT of 12 hrs.

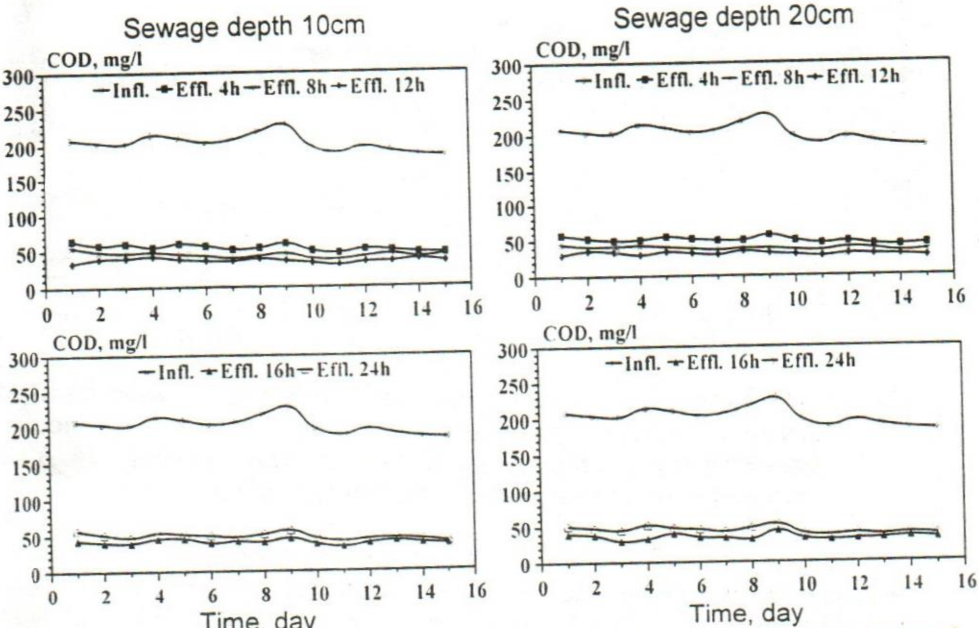
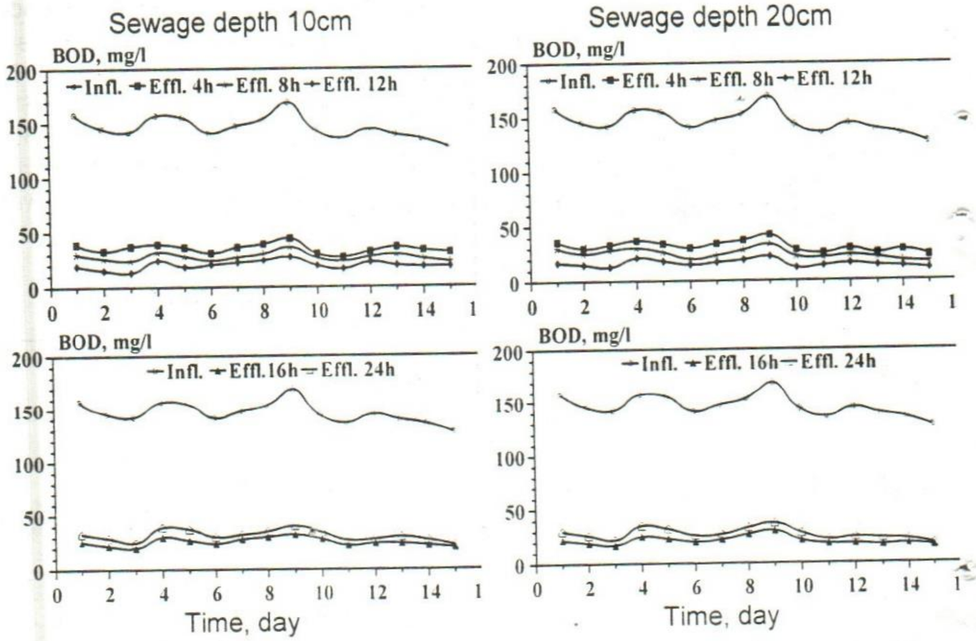


Fig. (2): Changes in the concentration of chemical oxygen demand (COD) for influent and effluents drained from both GBH models operated under different conditions of retention times (4, 8,12, 16 and 24hrs) and sewage depths (10 and 20cm).

Table (3): Removal efficiencies, maximum, and minimum concentrations (mg/L) of chemical oxygen demand (COD) for wastewater influent and effluent drained from both GBH models

System Retention time (RT)	Chemical oxygen demand, mg/L							
	GBH sewage depth							
	10cm				20cm			
	Min.	Max.	Avg.(±Sd)	Rem. %	Min.	Max.	Avg. (±Sd)	Rem. %
	Influent							
	184	228	202.7 (11.9)	—	184	220	202.7 (11.9)	—
	Effluents							
4 hrs	46	65	54.2 (5.5)	73.3	43	58	50.1(4.3)	75.3
8 hrs	38	55	44.3 (4.2)	78.2	34	45	39.2(2.9)	80.7
12 hrs	30	42	36.2 (3.1)	82.1	27	39	31.2 (2.5)	84.6
16 hrs	34	46	41.0 (3.4)	79.8	30	44	34.9 (3.8)	82.8
24 hrs	40	58	48.9 (5.1)	75.9	38	53	44.5(5.2)	78.1


Sewage depth 10cm

Sewage depth 20cm

Fig. (3): Changes in the concentration of biochemical oxygen demand (BOD) for influent and effluents drained from both GBH models operated under different conditions of retention times (4, 8,12, 16 and 24hrs) and sewage depths (10 and 20cm).

Removals of COD and BOD_5 by aquatic macrophyte filters were due to aerobic, facultative anaerobic and anaerobic respiratory activity. During these respiratory activities, organic matter (carbon) is utilized as an energy source by bacteria and converted to carbon dioxide or methane, depending on the electron acceptor availability (Reddy *et al.*, 1989). The removal efficiencies of COD and BOD_5 obtained in this study are in agreed with those obtained by

Butler *et al.,* (1990), Bahgat (1992), Kadlec and Rebert (1996), Vymazal (1999), Davison *et a.,l* (2001) and Healy and Cawley (2002). They reported that the removal efficiency of COD for wetlands were in ranges between 55.3 and 92.5 %, while the removal efficiencies of BOD_5 ranged between 60% and 94%.

Table (4): Removal efficiencies, maximum, and minimum concentrations of biochemical oxygen demand (BOD) for wastewater influent and effluent drained from both GBH models

System Retention time (RT)	Biochemical oxygen demand, mg/L							
	GBH sewage depth							
	10cm				20cm			
	Min.	Max.	Avg. (±Sd)	Rem. %	Min.	Max.	Avg. (±Sd)	Rem. %
	Influent							
	127	169	146.1 (10.4)	—	127	169	146.1 (10.4)	—
	Effluents							
4 hrs	27	44	34.9 (4.3)	76.1	23	42	31.1 (5.2)	78.7
8 hrs	22	36	27.3 (3.6)	81.3	17	33	24.3 (4.6)	83.4
12 hrs	13	27	19.6 (3.6)	86.6	11	22	15.8 (3.1)	89.2
16 hrs	20	32	25.3 (3.7)	82.7	16	30	20.9 (3.9)	85.7
24 hrs	22	40	31.1 (5.0)	78.7	18	37	27.0 (5.3)	81.5

4. Nitrogen removal

Changes in the concentrations (mg/L) of nitrogen fractions of wastewater influent and the effluents drained from both GBH models are graphed in Figs. (4,5 and 6) for ammonia, nitrate and total nitrogen. Tables (3,4 and 5) showed data summaries of the previous parameters.

Concentrations of NH_{4+}-N of influent wastewater ranged between 16.1 and 20.9 mg/L with an average of 18.3 (±1.6) mg/L, while the effluents drained from both GBH models exhibited different reductions in NH_4^+-N, NO_3^--N and Total nitrogen. Their values were greatly affected by the operated retention time and the sewage depth. The GBH model of 10cm sewage depth produced effluents with NH_4^+-N average values of 1.1 (±0.4), 0.8 (±0.3), 0.5 (±0.3), 0.6 (±0.3) and 0.7 (±0.4) mg/L, when this GBH model was operated at RT of 4, 8, 12, 16 and 24 hrs, respectively. The removal percentages of (NH_4^+-N) were calculated for this GBH model to be 94, 95.6, 97.3, 82.7, and 96.2 %, respectively.

The effluents drained from the GBH model of 20 cm SD showed higher values of (NH_4^+-N), whereas their average values were 2.7 (±0.7), 1.2 (±0.4), 0.8 (±0.4), 0.7 (±0.3) and 1.0 (±0.4) mg/L, when this GBH model was operated at RT of 4, 8, 12, 16 and 24 hrs, respectively. The removal percentages of (NH_4^+-N) were calculated for this GBH model to be 85.3, 93.4, 95.6, 96.2 and 94.5 %, respectively, following the previous order of operated retention times.

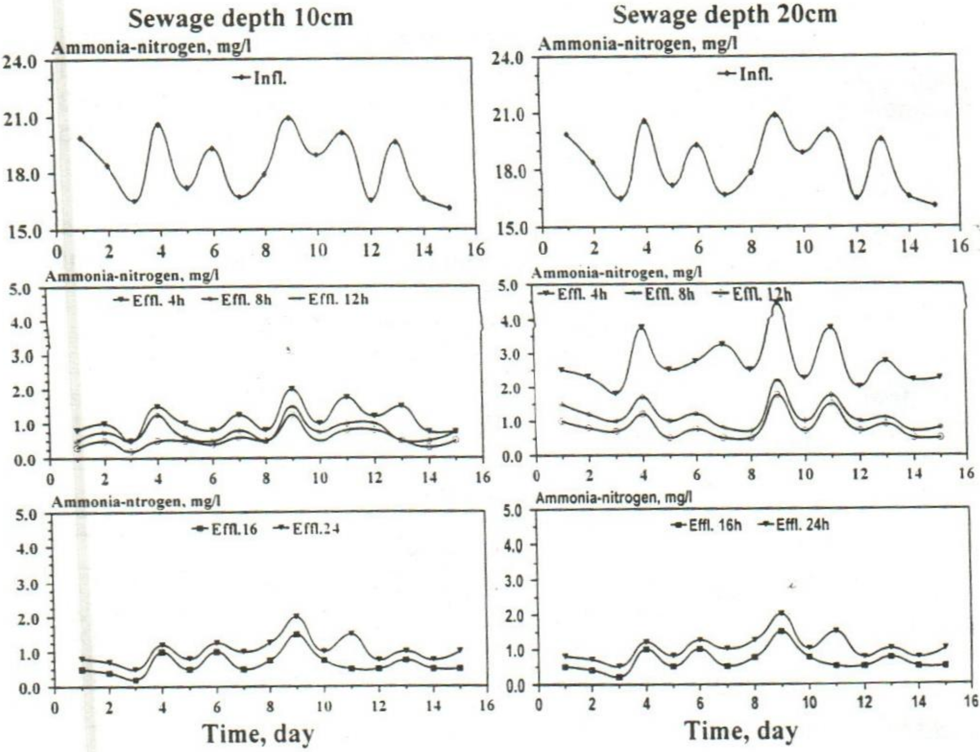


Fig. (4): Changes in the concentration of NH_4^+-N for influent and effluents drained from both GBH models operated under different conditions of retention times (4, 8,12, 16 and 24hrs) and sewage depths (10 and 20cm).

Concentrations of nitrate for influent wastewater ranged between 3.0 and 4.5 mg/L with an average of 3.5(±0.4) mg/L. The GBH model of 10cm SD produced effluents with NO_3^--N average values of 1.7(±0.3), 0.9(±0.2), 1.5(±0.3), 0.3(±0.2) and 0.7(±0.3) mg/L, when this GBH model was operated at retention times of 4, 8, 12, 16 and 24 hrs, respectively. The removal percentages of NO_3^--N were calculated to be 51.4, 74.2, 57.1, 91.4, and 80.0 %, respectively.

The effluents drained from the GBH model of 20 cm SD showed some changes in NO_3^--N values, whereas their average values were 1.2(±0.5), 0.9(±0.4), 1.6(±0.5), 0.4(±0.3) and 1.1(±0.3) mg/L, when this GBH model was operated at RT of 4, 8, 12, 16 and 24 hrs, respectively. The removal percentages of NO_3^--N were calculated for this GBH model to be 65.7, 74.3, 54.3, 88.6 and 68.6 %, respectively, following the previous order of operated retention times.

The losses determined in the concentrations of both NH_4^+-N and NO_3^--N as the wastewater was passed through the plant-gravel matrix of the GBH system lead to reductions in the total nitrogen (TN} values of the treated drained effluents. Concentrations of total nitrogen for influent wastewater ranged between 28.2 and 33.5 mg/L with an average of 30.6 (±1.7) mg/L.

The GBH model of 10cm sewage depth produced effluents with TN average values of 16.7 (±2.0), 6.6 (±0.9), 3.6 (±0.7), 6.3 (±1.5) and 4.0 (±0.8) mg/L, respectively, when this GBH model was operated at retention times of 4, 8, 12, 16 and 24 hrs, respectively. The removal percentages of TN following the previous order of operated retention times were 45.4, 78.4, 88.2, 79.4 and 86.9 % respectively.

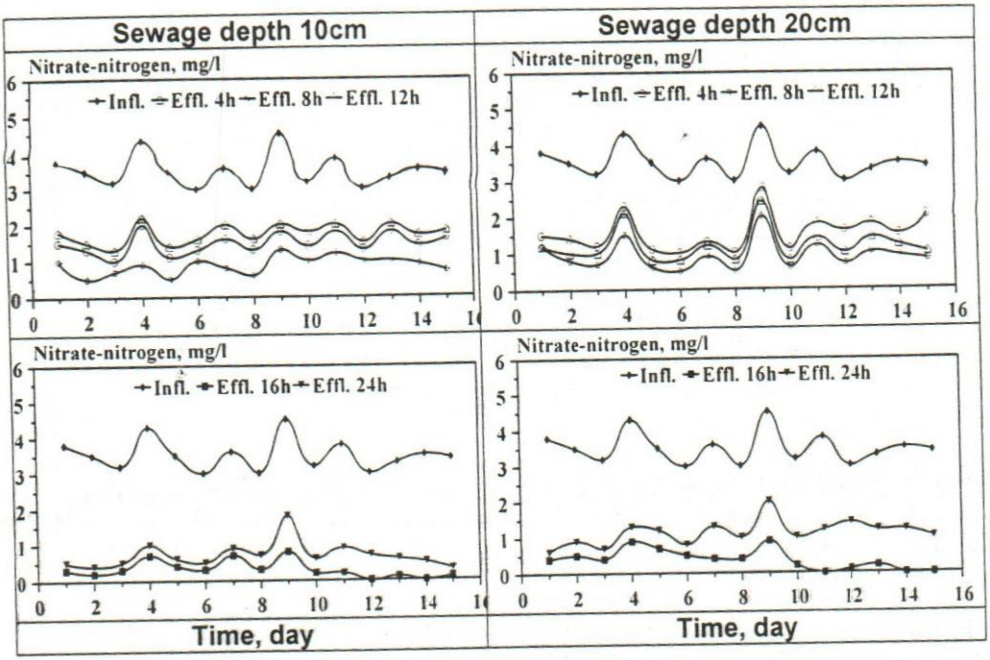


Fig. (5): Changes in the concentration of NO_3^--N for influent and effluents drained from both GBH models operated under different conditions of retention times (4, 8,12, 16 and 24hrs) and sewage depths (10 and 20cm).

The effluents drained from the GBH model of 20 cm SD showed lower values of TN, whereas their average values were 15.4 (±1.9), 6.0 (±0.8), 3.5 (±0.6), 5.6 (±1.1) and 3.9 (±0.6) mg/L, respectively, when this GBH model was operated at RT of 4, 8, 12, 16 and 24 hrs. respectively. The removal percentages of (TN) were calculated for this GBH model to be 49.7, 80.4, 88.6, 81.7 and 87.3 %, respectively.

The microbial activities influencing nitrogen cycle in wetland treatment system (GBH) involve a complex interaction of mineralizing, oxidizing and reducing processes. Ammonification, nitrification, denitrification, N_2-fixation and NO_3^- reduction are important microbial mediated processes in wetlands. Nitrogen can be lost from the system as a result of denitrification, a process mediated by facultative anaerobic heterotrophic bacteria which use NO_3-N as a terminal electron acceptor and produce gaseous N_2 or N_2O. Assimilation of ammonia and nitrate and ammonia volatilization from the GBH system could also play an important role for nitrogen loss.

The removal of NH_4^+-N and nitrate is documented to range between 52 and 85.3% as reported by Gersberg *et al.*, (1986), Kadlec and Rebert (1996), Davison *et al.*, (2001) and Healy & Cawley (2002).

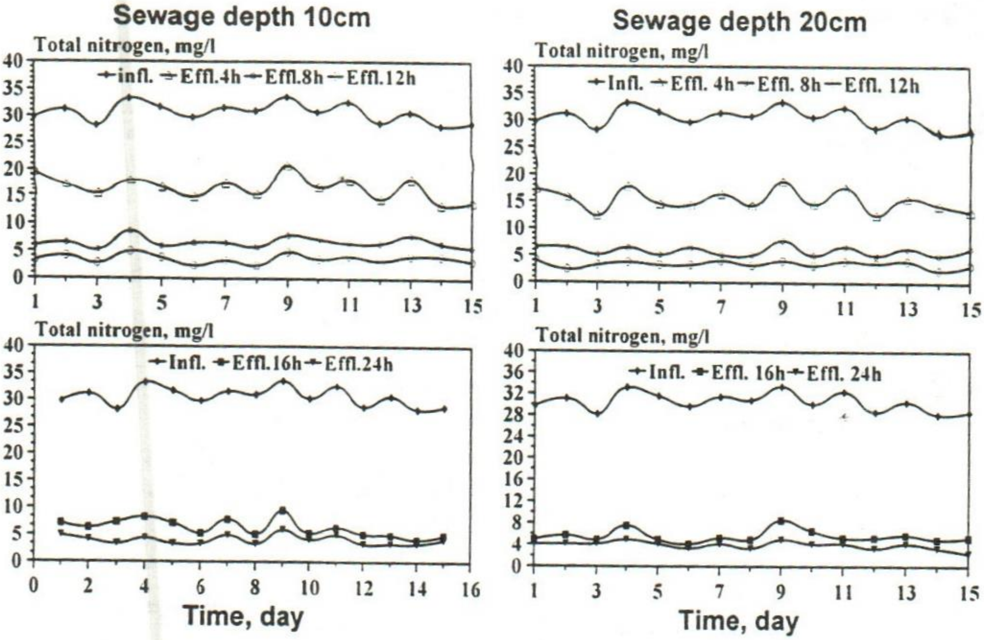


Fig. (6): Changes in the concentration of total nitrogen (TN) for influent and effluents drained from both GBH models operated under different conditions of retention times (4, 8,12, 16 and 24hrs) and sewage depths (10 and 20cm).

Table (5): Removal efficiencies, maximum, and minimum of the concentration of NH_4^+-N for influent and effluent drained from both GBH models

System Retention time (RT)	Ammoniacal-nitrogen, mg/L							
	GBH sewage depth							
	10cm				20cm			
	Min.	Max.	Avg. (±Sd)	Rem. %	Min.	Max.	Avg. (±Sd)	Rem.%
	Influent							
	16.1	20.9	18.3 (1.6)	—	16.1	20.9	18.3 (1.6)	—
	Effluents							
4 hrs	0.5	2	1.1 (0.4)	94.0	1.8	4.5	2.7 (0.7)	85.3
8 hrs	0.5	1.5	0.8 (0.3)	95.6	0.7	2.2	1.2 (0.4)	93.4
12 hrs	0.2	1.3	0.5 (0.3)	97.3	0.5	1.75	0.8 (0.4)	95.6
16 hrs	0.2	1.2	0.6 (0.3)	96.7	0.2	1.5	0.7 (0.3)	96.2
24 hrs	0.3	1.5	0.7 (0.4)	96.2	0.5	2.0	1.0 (0.4)	94.5

Table (6): Removal efficiencies, maximum, and minimum concentrations of NO_3^--N for wastewater influent and effluent drained from both GBH models

System Retention time (RT)	Nitrate (No_3^-) concentration, (mg/L)							
	GBH sewage depth							
	10cm				20cm			
	Min.	Max.	Avg (±Sd)	Rem. %	Min.	Max.	Avg. (±Sd)	Rem. %
	Influent							
	3.0	4.5	3.5 (0.4)	-	3.0	4.5	3.5 (0.4)	-
	Effluents							
4 hrs	1.3	2.2	1.7 (0.3)	51.4	0.8	2.4	1.2 (0.5)	65.7
8 hrs	0.5	1.3	0.9 (0.2)	74.3	0.5	2.0	0.9 (0.4)	74.3
12 hrs	1.0	2.0	1.5 (0.3)	57.1	1.0	2.8	1.6 (0.5)	54.3
16 hrs	0.0	0.8	0.3 (0.2)	91.4	0.0	0.9	0.4 (0.3)	88.6
24 hrs	0.3	1.8	0.7 (0.3)	80.0	0.6	2.0	1.1 (0.3)	68.6

Table (7): Removal efficiencies, maximum, and minimum concentrations of TN for wastewater influent and effluent drained from both GBH models

System Retention time (RT)	Total nitrogen (TN) concentration, (mg/L)							
	GBH sewage depth							
	10cm				20cm			
	Min.	Max.	Avg.(Sd)	Rem %	Min.	Max.	Avg. (±Sd)	Rem. %
	Influent							
	28.2	33.5	30.6 (1.7)	—	28.2	33.5	30.6 (1.7)	—
	Effluents							
4 hrs	13.6	20.9	16.7(2.0)	45.4	12.4	18.9	15.4 (1.9)	49.7
8 hrs	5.2	8.6	6.6 (0.9)	78.4	5.2	7.9	6.0 (0.8)	80.4
12 hrs	2.4	4.9	3.6 (0.7)	88.2	2.4	4.1	3.5 (0.6)	88.6
16 hrs	4.1	9.5	6.3 (1.5)	79.4	4.1	8.5	5.6 (1.1)	81.7
24 hrs	3.3	5.9	4.0 (0.8)	86.9	2.4	4.9	3.9 (0.6)	87.3

5. Removal of some indicator microorganisms:

Changes in the numbers of total and fecal coliforms bacteria for the wastewater influent and the effluents drained from both GBH models are shown in Figs. (7and 8) for total coliform and fecal coliform bacteria. Tables (8 and 9) showed data summaries for the previous microorganisms.

Numbers of total coliform bacteria for influent wastewater ranged between $50x10^4$ to $85x10^4$ cfu/ml with an average of $66x10^4$ ($\pm 7.4x10^4$) cfu/ml, while the effluents drained from both GBH models exhibited different reductions and their counts were greatly affected by the operated retention time and designed sewage depths. The GBH model of 10cm sewage depth produced effluents with total coliform bacteria average numbers of 32.5×10^3 ($\pm 4.8 \times 10^3$), 13.9×10^3 ($\pm 3.3 \times 10^3$), 19.1×10^2 ($\pm 3.6x10^2$), 48.1×10^2 ($\pm 6.6 \times 10^2$) and 72.3×10^2 ($\pm 12.5 \times 10^2$) cfu/ml, when this model was operated at RT of 4, 8, 12, 16 and 24 hrs, respectively. The removal percentages of total coliform bacteria were 95.08, 97.89, 99.71, 99.27 and 98.90 %, respectively.

The effluents drained from the GBH model of 20 cm SD showed little lower numbers of the total coliform bacteria, whereas their average numbers were 28.8 x 10^3 (±6.2 x 10^3), 12.7 x 10^3 (±2.3 x 10^3), 12.8 x 10^2 (±2.8 x 10^2), 44.1 x 10^2 (±6.6 x 10^2) and 65.6 x 10^2 (±9.5 x 10^2) cfu/ml, respectively, when this GBH model was operated at RT of 4, 8, 12, 16 and 24hrs, respectively. The averages of these numbers The removal percentages of total coliform bacteria were 95.64, 98.08, 99.81, 99.33 and 99.00 %, respectively, following the previous order of operated RT.

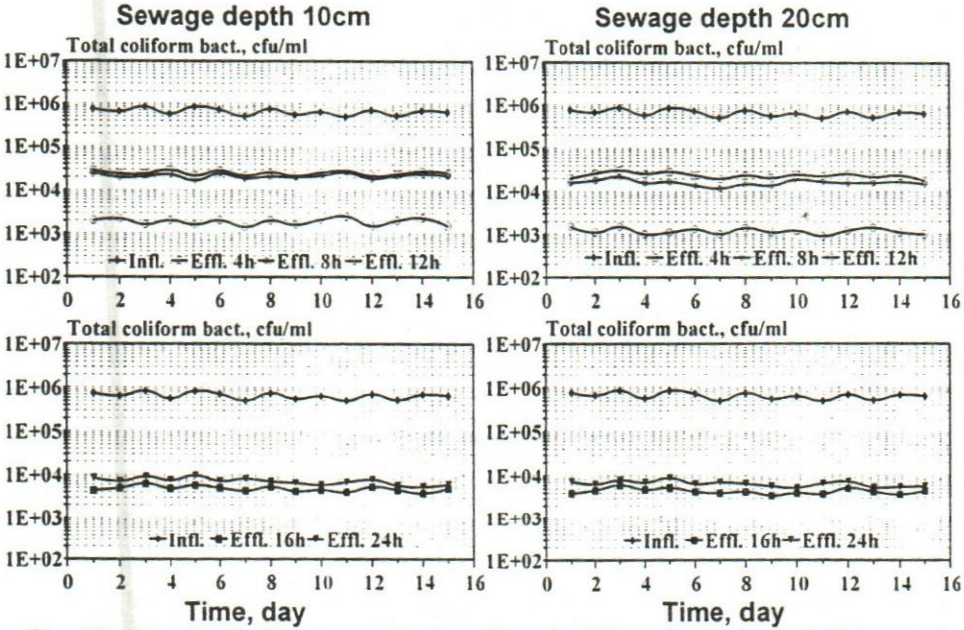


Fig. (7): Changes in the concentration of total coliform bacteria for influent and effluents drained from both GBH models operated under different conditions of retention times (4, 8,12, 16 and 24hrs) and sewage depths (10 and 20cm).

Numbers of fecal coliform bacteria for influent wastewater ranged between 20 x 10^4 and 31x10^4 cfu/ml with an average of 25.9 x 10^4 (±3.6 x 10^4) cfu/ml, while the effluents drained from both GBH models exhibited similar reductions trend observed with total coliform bacteria. The GBH model of 10cm sewage depth operated at retention times (RT) of 4, 8, 12, 16 and 24hrs produced effluents with fecal coliform bacteria averages of 12.03x10^3(±2.6x10^3), 5.6 x 10^3 (±9.4 x 10^2), 9.1 x 10^2 (±1.8 x 10^2), 23 x 10^2 (±2.1 x 10^2) and 32 x 10^2 (±3.4 x 10^2) cfu/ml, respectively. The removal percentages of fecal coliform bacteria following the previous order of operated RT were 95.36, 97.84, 99.65, 99.11 and 98.76 %, respectively, The effluents drained from the GBH model of 20 cm SD showed little lower numbers of the fecal coliform bacteria, whereas their average numbers were

10.3×10^3 ($\pm 1.4 \times 10^3$), 4.3×10^3 ($\pm 8.5 \times 10^2$), 7.73×10^2 ($\pm 1.4 \times 10^2$), 19.0×10^2 ($\pm 2.2 \times 10^2$) and 27×10^2 ($\pm 3.7 \times 10^2$) cfu/ml, respectively, when this model was operated at RT of 4, 8, 12, 16 and 24 hrs. The removal percentages of fecal coliform bacteria following the previous order of operated RT were 96.02, 98.34, 99.70, 99.27 and 98.96%, respectively.

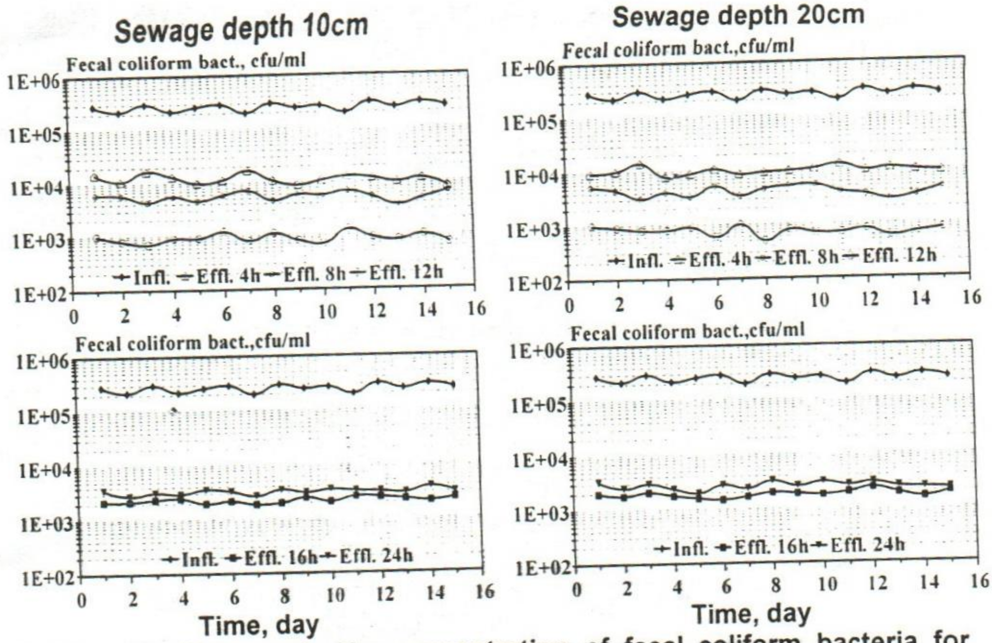


Fig. (8): Changes in the concentration of fecal coliform bacteria for influent and effluents drained from both GBH models operated under different conditions of retention times (4, 8,12, 16 and 24hrs) and sewage depths (10 and 20cm).

Several investigators have studied the removal of pathogenic indicators from natural and artificial wetlands and other alternative sewage treatment systems. Gresberg *et al.*, (1989) reported that at the hydraulic application rate of 5 cm ml^{-1} (5.5 day hydraulic residence time), the total coliform bacteria were reduced by 99.1% in the effluent of a vegetated (bulrush) bed Ibekwe *et al.*, (2003) reported that wetlands treatment achieved a 2 log (99%) decrease in total coliform bacteria and a 3 log (99.9%) decrease in fecal coliform bacteria.

Population decline of both coliforms in the artificial wetland is due to cell die-off, loss of viability, sedimentation, filtration and adsorption but also sunlight has been shown to have a lethal effect *on* coliforms, predators, bacterophages, and competition for limiting resources, as well as antibiosis may also exert bacterial effects (Bavor *et al*, 1989). It has been shown that root excretion of certain aquatic plant including Sciprus lacusteris and Phragmites communis can kill fecal indicators (*E. coli*) and some of pathogenic bacteria (Gerba *et al*, 1999).

Table (8): Removal efficiencies, maximum, and minimum counts of total coliform bacteria (cfu/ml x 10^2) for influent and effluent drained from both GBH models

System Retention time (RT)	Total coliform bacteria, cfu/ml x 10^3							
	GBH sewage depth							
	10cm				20cm			
	Min.	Max.	Avg. (± Sd)	Rem. %	Min.	Max.	Avg. (±Sd)	Rem.%
	Influent							
	500	850	661 (112)	-	500	850	6610 (1120)	-
	Effluents							
4 hrs	26	40	325 (4.8)	95.08	20	38	28.8 (62)	95.64
8 hrs	9	21	13.9(3.3)	97.89	9	16	12.7 (23)	98.08
12 hrs	1.3	2.7	19.1 (3.6)	99.71	0.9	1.6	1.27 (0.28)	99.81
16 hrs	3.8	6.3	48.2(6.6)	99.27	3.5	6.0	4.41 (0.66)	99.33
24 hrs	5.3	9.8	7.23(1.25)	98.90	5.3	8.8	6.56(0.95)	99.00

* cfu /ml: colony form unit per one milliliter

Table (9): Removal efficiencies, maximum, and minimum counts of fecal coliform bacteria (cfu/mlx10^2) for influent and effluent drained from both GBH models

System Retention Time (RT)	Fecal coliform bacteria, cfu /ml x 10^3							
	GBH sewage depth							
	10cm				20cm			
	Min.	Max.	Avg. (± Sd)	Rem. %	Min.	Max.	Avg. (±Sd)	Rem. %
	Influent							
	200	310	259 (36)	-	200	310	259 (36)	-
	Effluents							
4 hrs	8	17	12.0(2.6)	95.36	8	14.5	10.3(1.4)	96.02
8 hrs	3.7	7.1	5.6(0.94)	97.84	2.9	5.5	4.3(0.85)	98.34
12 hrs	0.7	1.3	0.9(0.18)	99.65	0.5	1.0	0.8(0.14)	99.70
16 hrs	19	26	23(2.1)	99.11	1.5	2.4	1.9(0.22)	99.27
24 hrs	27	38	32 (3.1)	98.76	20	33	27(3.7)	98.96

* cfu /ml: colony form unit per one milliliter.

CONCLUSION

The gravel bed hydroponic system used in this study represents a secondary step for primary wastewater treatment, which could be achieved for example by septic tank concept. A disinfection process was required after this secondary treatment to ensure the quality of water and eliminating any probability of negative health effect. Both GBH models represent a well-landscaped environment that affords successfully integrated function and aesthetic demand in an environmentally friendly system for treating wastewater. The GBH like systems could be used as solution to treat the domestic wastewater inflows of one household or low-population rural areas or to treat the outflows of some industries.

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الخصائص التشغيلية لنظام الأحواض الزلطية المائية (وحدة نصف صناعية)

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تعتبر نظم الأراضي الرطبة المصنعة لمعالجة مياه الصرف الصحي من التكنولوجيات منخفضة التكاليف ، كما يمكن إدخالها في المعالجة كخطوة معالجة ثانوية أو ثلاثية . ولدراسة الخصائص التشغيلية لهذه النظم تم تصنيع وحدتين من نظام الأحواض الزلطية المائية GBH(على مستوى النصف صناعي) من ألواح الحديد (سمك٤ مم) بأبعاد ٤ متر × ٣٠ سم عرض × ٤٠ سم ارتفاع ، وتم تزويد كل منهما بثلاث محابس للتحكم في دخول مياه الصرف الصحي إلى نظام المعالجة ، خروج المياه بعد المعالجة، وتحديد مستوى المياه داخل النظام. كما تم طلاء الوحدتين من الداخل بالبيتومين ، وملئهما بالحبيبات الزلطية وزراعتهما بريزومات نبات البردي وريهما بمياه حنفية لمدة شهرين كفترة لنمو النبات وثبات النظام . كذلك تم ضبط مستوى الماء في الوحدة الأولى والثانية ليكون عند ١٠ ، ٢٠ سم للوحدة الأولى والثانية على التوالى. وبعد هذه الفترة من النمو تم تغذية نظامى الـ GBH بمياه صرف صحي معالج معالجة أولية من محطة زنين لمعالجة مياه الصرف الصحي بنظام الدفعة الواحدة Batch mode . تم دراسة كفاءة النظامين في التخلص من المواد العالقة SS ، الاحتياج الكيميائي للأكسيجين COD ، الاحتياج البيوكيميائى للأكسجين BOD ، صور النتروجين (أمونيا – نترات – نيتروجين كلى) ودلائل الميكروبات الممرضة عند فترات مكوث للمياه بالنظام قبل صرفها المدد التالية ٤ ، ٨ ، ١٢ ، ١٦ ، ٢٤ ساعة على التوالي . تم عرض النتائج المتحصل عليها ومناقشتها بالتفصيل.