THE USE OF AN AEROBIC BIOLOGICAL FILTER FOR IMPROVING THE EFFLUENT QUALITY OF A TWO-STAGE ANAEROBIC SYSTEM

A. S. El-Gendy[1], T. I. Sabry[2] and F. A. El-Gohary[3]

[1] Associate Professor, Department of Environmental Engineering, Institute of Environmental Studies and Research, Ain Shams University, Cairo, Egypt.
E-mail: elgendy03@yahoo.ca
[2] Professor, Department of Public Works, Faculty of Engineering, Ain Shams University, Cairo, Egypt. E-mail: tsabry68@yahoo.com
[3] Emeritus Prof. Dr. Eng. Water Pollution Research Department (WPCD), Environmental Science Division (ESD), National Research Center (NRC), El Buhouth Street, Dokki, Cairo, Egypt E-mail: fgohary@hotmail.com

ABSTRACT

In Egypt, there is a growing realization between experts and decision makers that low-cost anaerobic treatment technologies such as the Up-flow septic tank followed by anaerobic baffled reactor is a promising technology. It is characterized by its high organic removal efficiency, simplicity, low capital and maintenance costs. However, anaerobic treatment produces wastewater which is not complying with the standards regulating discharge of treated wastewater into receiving water bodies. Therefore, a post treatment step is required.

In an attempt to develop a system which fulfill the requirements and at the same time is simple and cost-effective, a pilot-scale setup was designed and constructed at a wastewater treatment plant in Giza, Egypt. It consists of an up-flow anaerobic reactor; down-flow anaerobic packed-bed baffled reactor; a passive aeration and a biological filter system followed by a sedimentation tank. The biological filter is packed with plastic media. The system was operated at a hydraulic retention time of 24 hours in the anaerobic stages. To monitor the performance of the system, wastewater samples were collected from the influent and effluent of each treatment step along the pilot-scale setup. Available data indicated that the integration of the passive aeration and the biological filter system improved the effluent quality of the two-stage anaerobic system. The treated final effluent has a quality acceptable for disposal in agricultural drains according to Law 48 for the Year 1982. In addition, average overall removal efficiencies up to 85%, 69%, 88%, 91% and 89% were achieved for COD_{Total}, $COD_{Soluble}$, BOD_5, TSS and VSS, respectively.

Keywords: Wastewater Treatment, Low-Cost Treatment, Onsite Treatment System, Anaerobic Treatment, Biological Filter, Hydraulic Loading Rate, Passive Aeration

1. INTRODUCTION

Municipal wastewater collection and treatment facilities in Egypt are currently limited to the main urban centers. The coverage of urban areas in Egypt with improved sanitation gradually increased from 45% in 1993 to 56% in 2004, and expected to reach 100% by the end of 2012. However, on the other hand, rural Egypt is suffering from low coverage of proper sanitation. In 2008, only 11% of 4617 villages in Egypt, had wastewater treatment facilities. This coverage is expected to reach 20% by the end of 2012 (Abdel Wahaab [1]). As a result, the majority of villages and rural areas discharge their raw domestic wastewater directly into waterways. This results in severe water quality problems and degradation of health conditions around these rural areas. Consequently, there is an urgent need, in both the short and long term, to address this problem and find appropriate solutions, which are both economically and technically feasible for the Egyptian conditions. To face the challenge, several efforts have been carried out to develop appropriate technologies for wastewater treatment in rural areas.

A wide range of high to low technologies is available for sewage treatment in small communities. Management of sewage in small communities by using conventional high treatment technologies such as activated sludge consumes high energy during the operation. In addition, the conventional treatment systems require regular maintenance and skilled labors for their operation which are normally not available in such remote or isolated areas. (El-Gohary [2], El-Gohary et al. [3]). In addition, the shortage of financial resources is a big challenge facing the Egyptian government to cover rural areas with conventional wastewater treatment systems.

Many on-site anaerobic systems were used and tested successful at different countries as a decentralized sewage treatment (Sabry [4], Elmitwalli et al. [5], Lettinga et al. [6], Panswad and Komolmethee [7], Young and McCarty [8]). Upflow Septic tank followed by anaerobic Baffled Reactor (USBR) as a new concept of low cost technology employing two stages anaerobic treatment for sewage treatment proved to be able to efficiently treat wastewater (Sabry and Sung [9]). This technology is also easy to implement and operate. Therefore, it would be more convenient for the conditions of rural areas in Egypt. The satisfactory performance of USBR in sewage treatment (Sabry [10], Ghobrial et al. [11], Sabry [12], Sabry and Sung [9]), indicates that this system could be used in a small scale to serve a household or in a big scale to serve a small community. However, the USBR system in its current shape (Sabry and Sung [9], Sabry [10]), occupies a relatively large area of land. Bearing to the fact that land availability in a major part of the inhabited rural areas in Egypt (for example, the Nile Delta) is limited and expensive, the use of the USBR for sewage treatment in these areas might be unfavorable. Therefore, a new treatment system with a smaller footprint and a similar concept of the USBR has been constructed and tested (Sabry et al. [13]). This treatment system is a compact system. It consists of two-stage anaerobic reactors; an up-flow anaerobic reactor followed by a down-flow anaerobic packed-bed baffled reactor. To minimize its footprint area, this system was designed so that most of its volume occupies vertical space instead of horizontal space. Although this system follows a concept similar to the USBR concept, the experimental data from testing the system indicated the requirement for adding an aerobic treatment to improve the effluent quality of the two-stage anaerobic reactors (Sabry et al. [13]). Therefore, the current study provides a thorough investigation include experimental testing on the use of a passive aeration followed by an aerobic biological filter for improving the effluent quality of the two-stage anaerobic system at different operating conditions.

2. MATERIALS AND METHODS

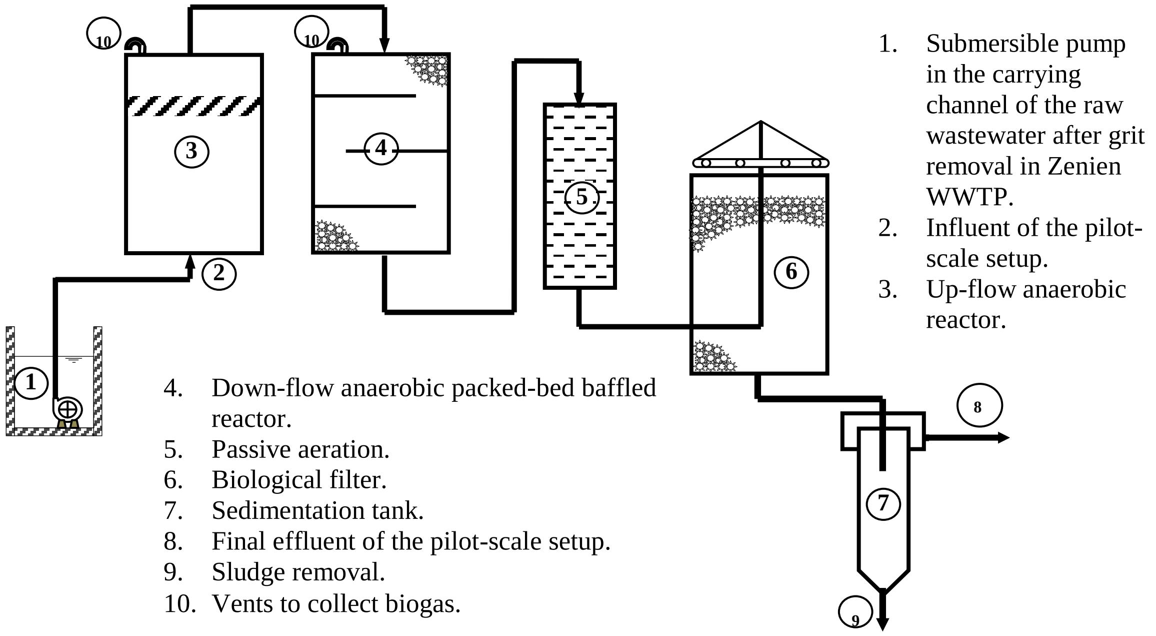
A compact-shape pilot-scale setup was designed and constructed at Zenien wastewater treatment plant (Zenien WWTP) in Giza Governorate, Egypt. It was operated under ambient environmental conditions. The pilot-scale setup consists of two stages of anaerobic reactors followed by aerobic reactors.

2.1 Description of the Pilot-Scale Setup

Figure 1 shows a schematic diagram for the arrangement of the different units in the pilot-scale setup. The raw wastewater is pumped to the pilot-scale setup from the carrying channel between grit removal and primary sedimentation tank at Zenien WWTP. At the pilot plant, the raw wastewater flows first into the two stages of anaerobic reactors. The first stage is an up-flow anaerobic reactor as shown in Figure 1. The up-flow mode of operation improves the physical removal of suspended solids through gravity settling. In addition, a plate settler was installed at the reactor effluent to provide the same function of a solid-liquid separator in an Up-flow Anaerobic Sludge Blanket (UASB) reactor. The plate settler can reduce escaping of solids to the second stage of the anaerobic reactors. The accumulated suspended solids in the up-flow anaerobic reactor form a sludge blanket which improves the removal of suspended solids through an entrapment mechanism (Elmitwalli et al. [5], Lettinga et al. [6], Zeeman and Lettinga [14], Van Handel and Lettinga [15]).

The second stage is a down-flow anaerobic packed-bed baffled reactor as shown in Figure 1. This stage serves as a polishing step thereby converting the remaining volatile fatty acids and escaped suspended biodegradable organics from the up-flow anaerobic reactor to biogas. The down-flow anaerobic packed-bed baffled reactor is divided into sections through horizontal baffles. This baffled reactor can be regarded as a quasi-plug flow reactor configuration that provides kinetic benefits to enable microorganisms to degrade the residual organics to the lowest possible level. This reactor was packed with plastic media. Figure 2 shows a photo of the plastic media that has been used in the down-flow anaerobic packed-bed baffled reactor.

To improve the effluent quality of the anaerobic stages, a biological filter system is proposed as an additional treatment. The effluent of the anaerobic reactors is expected to contain no to very low concentrations of dissolved oxygen. The low oxygen contents of the anaerobic stages’ effluent will negatively affect the performance of the proposed biological filter system. Therefore, the oxygen contents of this effluent have to be increased before using the biological filter system. The added oxygen will activate the aerobic attached-growth microorganisms which have the key role in the wastewater treatment by the biological filter. Therefore, the effluent of the anaerobic stages is passed through an aeration step before the biological filter system (Figure 1). The aeration is provided to the effluent of the anaerobic stages through a passive mean. The biological filter system composed of a standard rate-attached growth-biological filter followed by a sedimentation tank (Figure 1). A sedimentation tank is provided after the biological filter to remove the sloughed biomass and dead cells from the attached growth biofilm on the plastic media inside the biological filter. The biological filter was filled with plastic media similar to that shown in Figure 2 and will be described later.



1. Submersible pump in the carrying channel of the raw wastewater after grit removal in Zenien WWTP.
2. Influent of the pilot-scale setup.
3. Up-flow anaerobic reactor.
4. Down-flow anaerobic packed-bed baffled reactor.
5. Passive aeration.
6. Biological filter.
7. Sedimentation tank.
8. Final effluent of the pilot-scale setup.
9. Sludge removal.
10. Vents to collect biogas.

Figure 1. Schematic Diagram of the Pilot-Scale Setup

2.2 Plastic Media

Each grain of the plastic media has two coaxial rings with 11 ribs connecting the two rings as shown in Figure 2. The outer ring has a diameter of 5.5 cm, while the inner ring has a diameter of 3 cm. The thickness of the plastic in this media is around 1 to 2 mm. This plastic media is usually used for supporting the steel bars during concrete pouring in construction works. It is also made of plastics collected from garbage, recycled and then molded in the shape shown in Figure 2. The manufacturing of this media from recycled materials collected from garbage is reflected on its cheap price. Also the plastic media has a lighter weight when compared with traditional media such as rocks or gravel. The light weight of the media will reduce the forces and stresses acting on the structural elements of the biological filter and as a result smaller dimensions can be used for these elements. This will dramatically reduce the construction cost of the biological filter.

Figure 2. A Photo of the Plastic Media

2.3 Design and Operating Parameters

The system was operated for about 166 days at a flow rate of 0.375 m^3/day. The hydraulic retention time for the two-stage anaerobic phase was 24 hours. To evaluate the effect of using a biological filter system on improving the effluent quality of the two-stage anaerobic system, several hydraulic and organic loading rates of wastewater on the biological filter were tested. The biological filter was tested at hydraulic loading rates of 1.46, 2.18 and 4.37 $m^3/m^2/d$. These values correspond to average organic loading rates of 0.23, 0.33 and 0.64 kg BOD/m^3/day, respectively. The effluent of the two-stage anaerobic treatment was distributed on three identical compartments of a biological filter. Each compartment has an area of 0.086 m^2 and a depth of 1 m. To examine the indicated different hydraulic loading rates on the biological filter, the effluent of the two-stage anaerobic treatment was distributed on three, two or one compartment.

2.4 Sampling and Sample Analyses

The performance of the system was evaluated by carrying out an intensive program for sampling and analyses. The sampling program was designed to achieve maximum information about variation in influent and effluent characteristics and the performance of each treatment step. Sample analyses were carried out according to the Standard Methods for Water and Wastewater Examination (APHA et al. [16]). The collected samples were analyzed for total chemical oxygen demand (COD_{Total}), soluble chemical oxygen demand ($COD_{soluble}$), 5-day Biochemical oxygen demand (BOD_5), total suspended solids (TSS), volatile suspended solids (VSS), water temperature, dissolved oxygen and pH.

2.5 Evaluation of the Treatment Performance

To evaluate the performance of the pilot plant in the treatment of the raw wastewater, the effluent concentrations of the analyzed pollutants are compared with the regulatory limits. The limits provided by Law 48 for the Year 1982 of the Egyptian Laws are used for the comparisons. Law 48 for the Year 1982 indicates that the COD_{Total}, BOD_5, TSS and water temperature should not exceed 80 mg/L, 60 mg/L, 50 mg/L and, 35 ^oC respectively, if the treated effluent is to be disposed in agricultural drains. Law 48 for the Year 1982 also indicates that the pH value of the treated effluents disposed in agricultural drains should fall into the range of 6 - 9.

3. RESULTS AND DISCUSSION

3.1 Experimental Conditions

The temperature of the influent wastewater to the biological filter ranged between 15 ^{o}C and 25 ^{o}C with an overall average of 20 ± 3 ^{o}C. The average pH value of the raw wastewater was found to be 7.1 ± 0.1. The effluent of the anaerobic phase had an average pH value of 7.4 ± 0.1. The pH value continues to rise at the effluent of the biological filter system to reach an average value of 7.5 ± 0.1. The temperature and pH of the influent and effluent of the biological filter support the growth of the aerobic attached-growth microorganisms responsible for the biological treatment. Therefore, the treatment kinetics will not be affected.

3.2 Effect of Passive Aeration

In passive aeration, the effluent of the anaerobic stages is allowed to trickle through perforated trays placed on top of each other. This allows natural diffusion of oxygen from ambient air into the trickled drops of water. As a result, the concentration of the dissolved oxygen in the effluent of the anaerobic stages will increase before reaching the biological filter. Hence the attached growth on the plastic media inside the biological filter depends on aerobic microorganisms; the pre-aeration will improve the performance of the biological filter. The average concentration of dissolved oxygen in the effluent of the two-stage anaerobic reactors was found to be 0.87 mg/L. The passive aeration of this effluent by trickling through the perforated trays increased the oxygen concentration to 5.22 mg/L before flowing through the biological filter.

3.3 Effect of Biological Filter System on the Effluent Quality of the Anaerobic Phases and Compliance with the Regulation Limits

Table 1 shows the average, maximum and minimum concentrations of the raw wastewater, effluent of the anaerobic stages and final effluent of the pilot-scale setup at different hydraulic loading rates of the biological filter.

Table 1 Wastewater characteristics for different stages of treatment in the pilot-scale setup at different hydraulic loading rates

Hydraulic Loading Rate ($m^3/m^2.d$)	Concentration (mg/L)	COD-Total			COD-Soluble			BOD		
		Raw	Anaerobic stages effluent	Final Effluent	Raw	Anaerobic stages effluent	Final Effluent	Raw	Anaerobic stages effluent	Final Effluent
1.46	Average	447	327	77	122	89	53	269	156	37
	Maximum	1332	562	130	277	133	90	750	270	69
	Minimum	255	194	41	60	62	27	135	110	26
2.18	Average	389	275	58	106	87	33	222	152	28
	Maximum	475	453	98	126	142	63	294	255	49
	Minimum	300	128	24	89	48	18	174	90	12
4.37	Average	463	255	76	111	93	47	230	146	36
	Maximum	652	515	155	135	131	103	312	300	56
	Minimum	316	123	25	91	65	13	178	79	19

Hydraulic Loading Rate ($m^3/m^2.d$)	Concentration (mg/L)	TSS			VSS		
		Raw	Anaerobic stages effluent	Final Effluent	Raw	Anaerobic stages effluent	Final Effluent
1.46	Average	304	205	41	145	95	22
	Maximum	736	400	126	277	249	70
	Minimum	95	84	14	40	16	7
2.18	Average	217	177	20	93	79	10
	Maximum	310	324	40	160	195	21
	Minimum	110	69	6	39	25	3
4.37	Average	248	132	30	94	62	13
	Maximum	398	290	75	150	130	35
	Minimum	112	39	8	43	14	4

The raw wastewater had average concentrations of 433 mg/L, 133 mg/L, 240 mg/L, 257 mg/L and 111 mg/L for COD_{Total}, $COD_{Soluble}$, BOD_5, TSS and VSS, respectively, throughout the testing period. The anaerobic stages remove part of the organic matter and suspended solids from the raw wastewater and provide an effluent with average COD_{Total}, $COD_{Soluble}$, BOD_5, TSS and VSS concentrations of 285 mg/L, 90 mg/L, 151 mg/L, 171 mg/L and 78 mg/L, respectively, throughout the testing period. As shown from the results in Table 1, the effluent of the two-stage anaerobic reactors does not comply with the limits provided by the Law 48 for the Year 1982. Therefore, there is a need to improve the quality of this effluent by providing the passive aeration followed by the biological filter system.

Figure 3 shows the variations in the concentrations of the COD_{Total}, BOD_5 and TSS in the effluent of the two-stage anaerobic reactors and in the effluent of the biological filter system at different hydraulic loading rates during the study period. Figure 3 also shows the regulatory limits for COD_{Total} and BOD_5 provided by Law 48 for the Year 1982. The data presented in Figure 3 indicated that the concentrations of COD_{Total} in the final effluent, except for few data points, are lower than the regulatory limits of Law 48 for the Year 1982 for all of the tested hydraulic loading rates. Similar observations were obtained for BOD_5 and TSS at different hydraulic loading rates as shown in Figure 3. However, the BOD_5 and TSS concentrations in the final effluent is always less than the regulatory limits when the biological filter was tested at a hydraulic loading rate of 2.18 m^3/m^2.d. Table 1 shows that the average COD_{Total} concentration of the final effluent of the pilot-scale treatment ranged between 58 mg/L and 77 mg/L for the different tested hydraulic loading rates. It also shows that the average BOD_5 and TSS concentrations of the final effluent ranged between 28 mg/L and 37 mg/L for BOD_5 and between 20 mg/L and 41 mg/L for TSS. These values are less than the limits provided by Law 48 for the Year 1982. Therefore the biological filter integrated with passive aeration can improve the effluent quality of the anaerobic stages and can provide effluents with qualities acceptable for disposal in agricultural drains according to Law 48 for the Year 1982 with respect to COD_{Total}, BOD_5 and TSS.

The results in Table 1 and Figure 3 show that the fluctuations in the concentrations (the difference between the maximum and minimum values) of different pollution parameters in the final effluent are much less than that in the effluent of the anaerobic stages. This indicates that the biological filter system is working as a buffer to absorb any fluctuations in the anaerobic effluent and produce effluent with nearly constant quality.

3.4 Effect of the Hydraulic Loading Rate on the Performance of the Biological Filter System

Figure 4 shows the average removal efficiencies of all pollution parameter from wastewater. Figure 4 also shows the standard deviations of these removal efficiencies. The removal efficiencies presented in Figure 4 include two removal efficiencies.

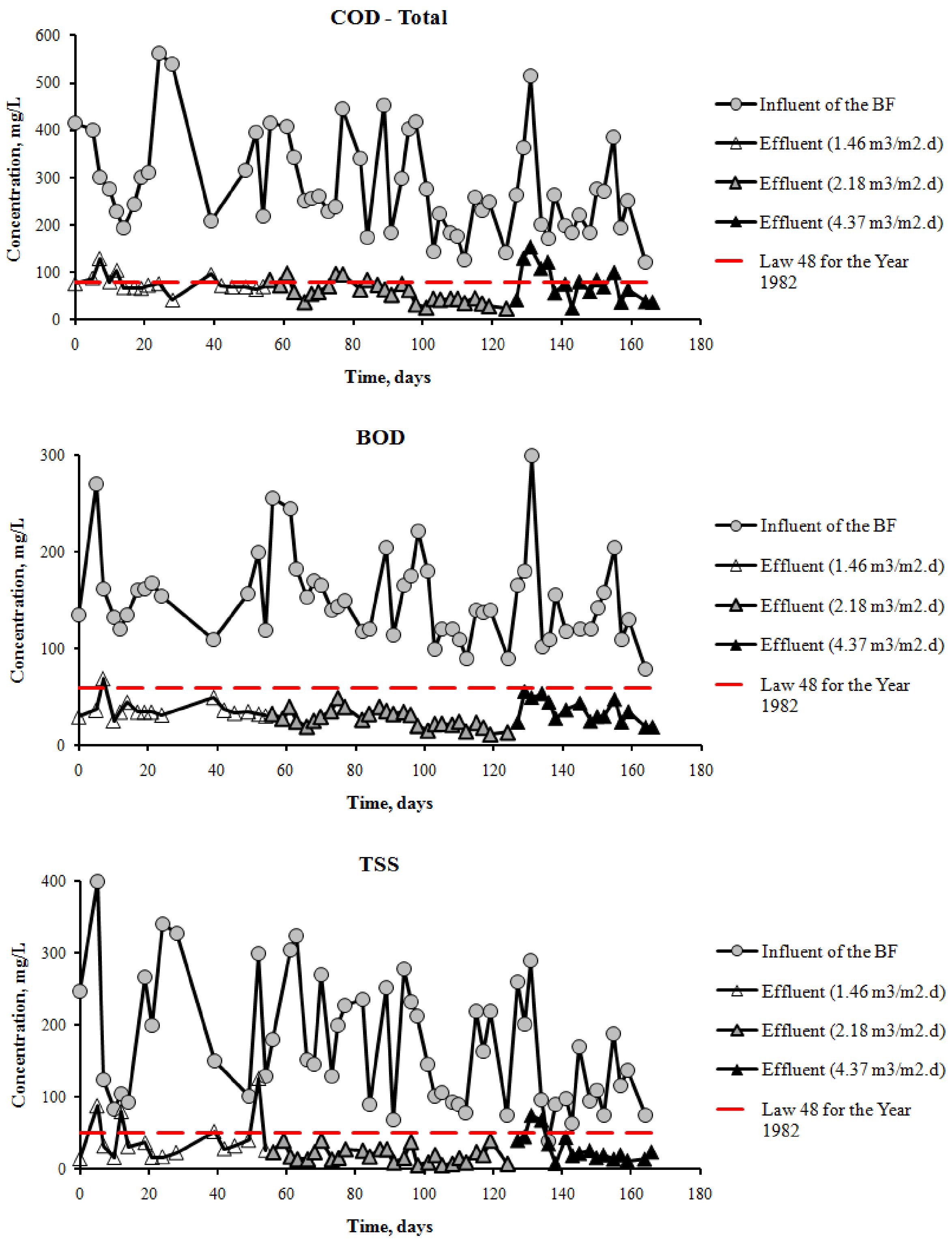


Figure 3. Changes in the influent and effluent concentrations of different pollution parameters at different operating conditions of the biological filter

The first is the removal efficiency through the integrated passive aeration and biological filter system at different hydraulic loading rates of the biological filter. The second is the overall removal efficiency through the whole treatment system (including both anaerobic and aerobic phases) at different hydraulic loading rates of the biological filter. As shown in Figure 4, the highest removal efficiencies of the different pollution parameters occurred at a hydraulic loading rate of 2.18 m^3/m^2.d.

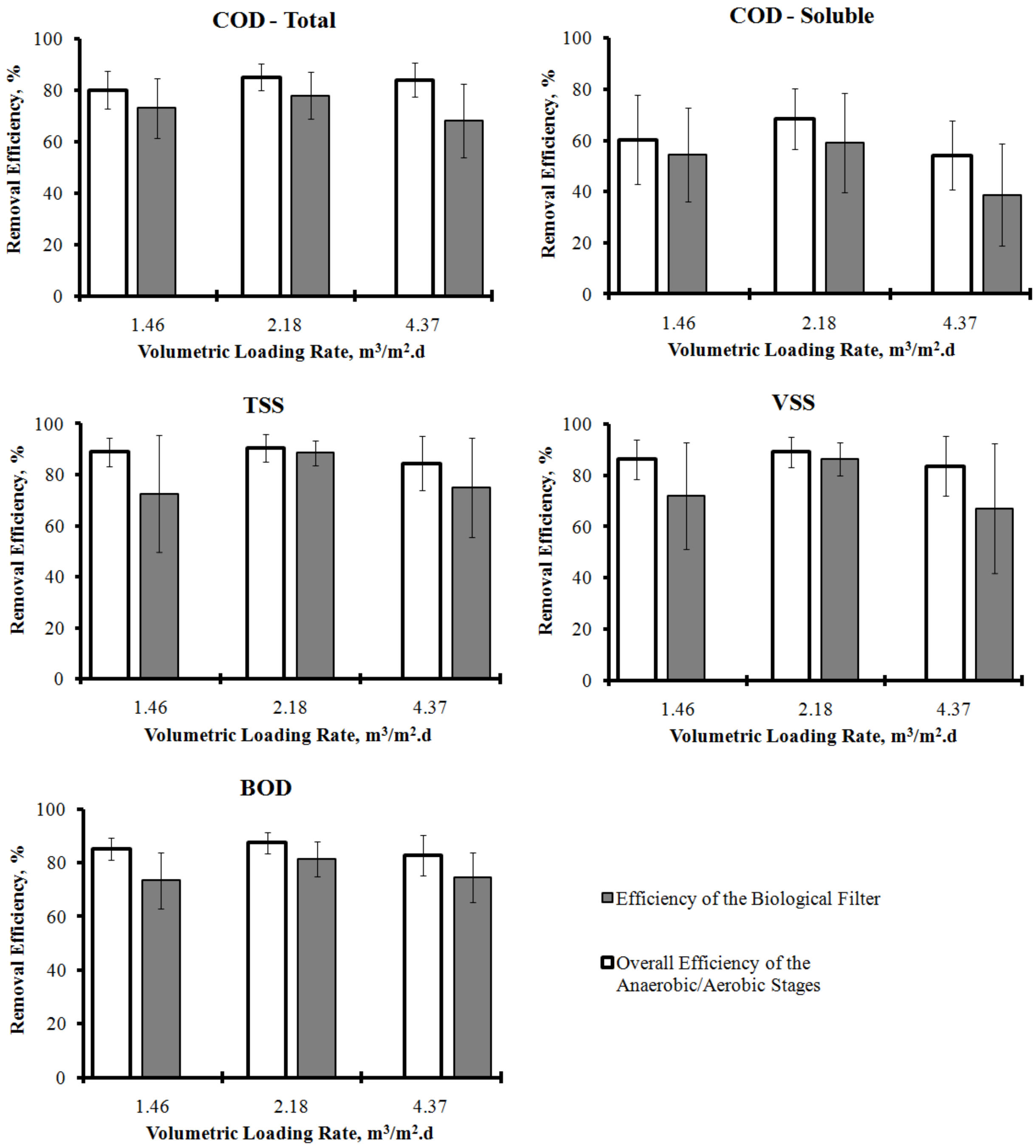


Figure 4. Specific and overall removal efficiencies of different pollution parameters at different operating conditions of the biological filter

In addition, as shown in Table 1, the lowest fluctuations in the concentrations of the different pollution parameters of the final effluent occurred at the same hydraulic loading rate (2.18 m^3/m^2.d). Therefore, it is recommended to operate the biological filter at a hydraulic loading rate of 2.18 m^3/m^2.d.

The integration of passive aeration and biological filter can provide average removal efficiencies up to 78% ± 9%, 59% ± 19%, 81% ± 6%, 89% ± 5% and 86% ± 7% for COD_{Total}, $COD_{soluble}$, BOD_5, TSS and VSS, respectively. In addition, the integration of the anaerobic and aerobic phases of the treatment can provide overall average removal efficiencies up to 85% ± 5%, 69% ± 12%, 88% ± 4%, 91% ± 6% and 89% ± 6% for COD_{Total}, $COD_{soluble}$, BOD_5, TSS and VSS, respectively. This is comparable to the BOD_5 removal efficiency that can be provided by conventional systems such as activated sludge (60% - 95%), trickling filter (65% - 90%) and aerated ponds (80% - 95%) (Metcalf and Eddy [17], Sabry [4], Sabry [12]).

The removal efficiency in the current system can be achieved in a completely passive approach except for the pumping device at the influent which may be required in any treatment system. In addition, the biodegradable organic matter in the wastewater can be transformed into biogas (methane) in the anaerobic phase reactors of the treatment (Sabry [4]). The biogas can be collected and utilized as a source of energy (Metcalf and Eddy [17]). Therefore, the current treatment system is highly competing with other conventional systems with regard to the performance, compact shape and minimal energy consumption.

4. CONCLUSIONS

This study was conducted to investigate the effect of using biological filter system for improving the effluent quality of two-stage anaerobic reactors. A pilot-scale treatment system composed of an up-flow anaerobic reactor; down-flow anaerobic packed-bed baffled reactor; a passive aeration and a biological filter packed with plastic media followed by a sedimentation tank was tested. The results show that the use of passive aeration after the anaerobic phases of the treatment increases the dissolved oxygen contents of the anaerobic effluent by 6 folds to reach an average concentration of 5.22 mg/L. The added oxygen will activate the aerobic attached-growth microorganisms which play the main role of wastewater treatment in the biological filter system. The biological filter was tested at three different hydraulic loading rates, 1.46, 2.18 and 4.37 m^3/m^2.d. It was found that the use of biological filter at a hydraulic loading rate of 2.18 m^3/m^2.d provides the highest removal efficiencies of COD_{Total}, $COD_{soluble}$, BOD_5, TSS and VSS from wastewater. With the operation of the biological filter at this loading rate, average overall removal efficiencies of 85%, 69%, 88%, 91% and 89% can be achieved for COD_{Total}, $COD_{soluble}$, BOD_5, TSS and VSS, respectively. Overall, the integration of anaerobic and aerobic phases of the treatment can provide effluents with quality acceptable for disposal in agricultural drains according to Law 48 for the Year 1982 with respect to COD_{Total}, BOD_5 and TSS.

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