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Chapter 16

Polyurethane Trickling Filter in Combination with Anaerobic Hybrid Reactor for Treatment of Tomato Industry Wastewater

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/47982

1. Introduction

The tomato industry is among the most polluting food industries in its huge amount of water consumption. This wastewater is predominantly loaded with organic wastes and is rich in organic content (Bozinis et al., 1996). Biological treatment processes are widely used for the treatment of agro-industry wastewaters, such as tomato industry wastewater which contain high concentrations of biodegradable organic matter (BOM) (Satyanarayan et al., 2005; Tawfik & El-Kamah 2011). Anaerobic treatment of high strength wastewater is widely accepted in the industry (Tawfik et al., 2008; Mehrdad et al., 2007; Del Pozo et al., 2003; Bernet &Paul, 2006). It has several advantages over aerobic processes, which include the use of less energy due to omission of aeration, the conversion of organic matter to methane which is an energy source by itself and can be used to supply some of the energy requirement of the process. Lower production of sludge, which reduces sludge disposal costs greatly and low level of maintenance, are other benefits of anaerobic processes (Tawfik et al., 2006; Cakira & Stenstromb, 2005; Shin et al., 2005). Moreover, high substrate removal efficiencies would be achieved in anaerobic reactors with short hydraulic retention time (HRT) and high organic loading rate (OLR) (Tawfik et al., 2010). One of the most efficient and quite flexible designs available is an anaerobic hybrid (AH) reactor which combines advantages of both anaerobic filter (AF) and up-flow anaerobic sludge blanket (UASB) designs (Chang ,1989; Hawkes et al., 1995; Wu et al., 2000; Tawfik et al., 2011; Mahmoud et al., 2009). The presence of polyurethane media in the upper portion of AH reactor, in addition to its physical role for biomass retention, also exerts some biological activity which contributes to chemical oxygen demand (COD) reduction in a zone where generally active biomass is lacking in a calssical UASB reactor (Elmitwalli et al., 1999; Tawfik et al., 2009). However; the effluent quality of anaerobic reactor is still not complying in terms of COD,

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total suspended solids (TSS) and nitrogen for discharge into drainage canals. Therefore, post-treatment is needed. Trickling filter (TF) is one of the aerobic biological treatment systems that are widely used for post-treatment of anaerobically pretreated effluent. However, the TF still has some drawbacks such as difficulty in maintenance of appropriate biofilm thickness under limitation of oxygen supply and biofilm detachment from the packing materials. In this investigation polyurethane trickling filter (PTF) was proposed. It has several advantages compared to conventional TF. In TF of which micro-organisms attach themselves only to a media surface creating a biological filter or slime layer, but in PTF module, the micro-organisms are retained outside and inside the polyurethane media which create long sludge residence time (SRT>100 days) (Tawfik et al., 2006) and consequently, achieve a complete nitrification and produce a very low amount of sludge (Tawfik et al., 2006). Once again, PTF brings the following advantages compared to conventional TF, the amount of active biomass brought in contact with the wastewater is very high and the biological process is very fast, thus very short retention time is needed which gives small plants with no investment cost (Tawfik et al., 2010). The process is in contrast to conventional TF which needs a very low OLR to achieve a nitrification process (Tawfik et al.,2011; Chernicharo &Nascimento, 2001). Moreover, it is easy to enlarge the capacity of PTF system in case the flow and/or the organic load would increase in the future.

The objectives of this investigation are to 1. assess the efficiency of a combined system consisting of AH reactor and PTF for the treatment of tomato industry wastewater at different HRTs and OLRs with emphasis on the COD fractions (COD_{total}; $COD_{soluble}$ and $COD_{particulate}$); TSS and total nitrogen (TN) removal. In addition, the mechanism for the removal COD, TSS and nitrification efficiency along the height of PTF is investigated.

2. Materials and methods

2.1. Tomato wastewater industry

Tomato-processing wastewaters are typical high strength wastewater generated from the food canning industry. Composite wastewater samples from tomato manufacturing company were collected and analyzed for parameters considered necessary for wastewater characterization and system design for a year. Characteristics of the Tomato wastewater industry showed that 73.4 % of the TSS, was volatile organics; and 64% of the COD was insoluble form. Soluble NH_4 –N constituted 74% of TN. The tomato processing industry wastewater were used as substrates for the combined system consisting of AH reactor as a pretreatment and PTF as a post-treatment unit (Fig. 1).

2.2. Anaerobic hybrid (AH) reactor

5 l AH reactor was designed and manufactured from polyvinyl chloride (PVC) as described earlier by Tawfik et al., (2011) and illustrated in Fig. 1. The AH reactor consisted of a sludge blanket at the bottom, and floating polyurethane carriers at the top to overcome washout of sludge from the reactor. The surface area of polyurethane carriers in the AH reactor was

0.57m[2]. $NaHCO_3$ was added to adjust the influent pH in the range of 6–7. The seed sludge was taken from an up-flow anaerobic sludge blanket (UASB) reactor treating juice industry wastewater. The sludge is typically flocculent with mixed liquor suspended solids (MLSS) of 16.8 g/l, mixed liquor volatile suspended solids (MLVSS) of 10.8 g/l and VSS/TSS ratio of 0.64. Three liters of the sludge was pumped into the AH reactor as an inoculum.

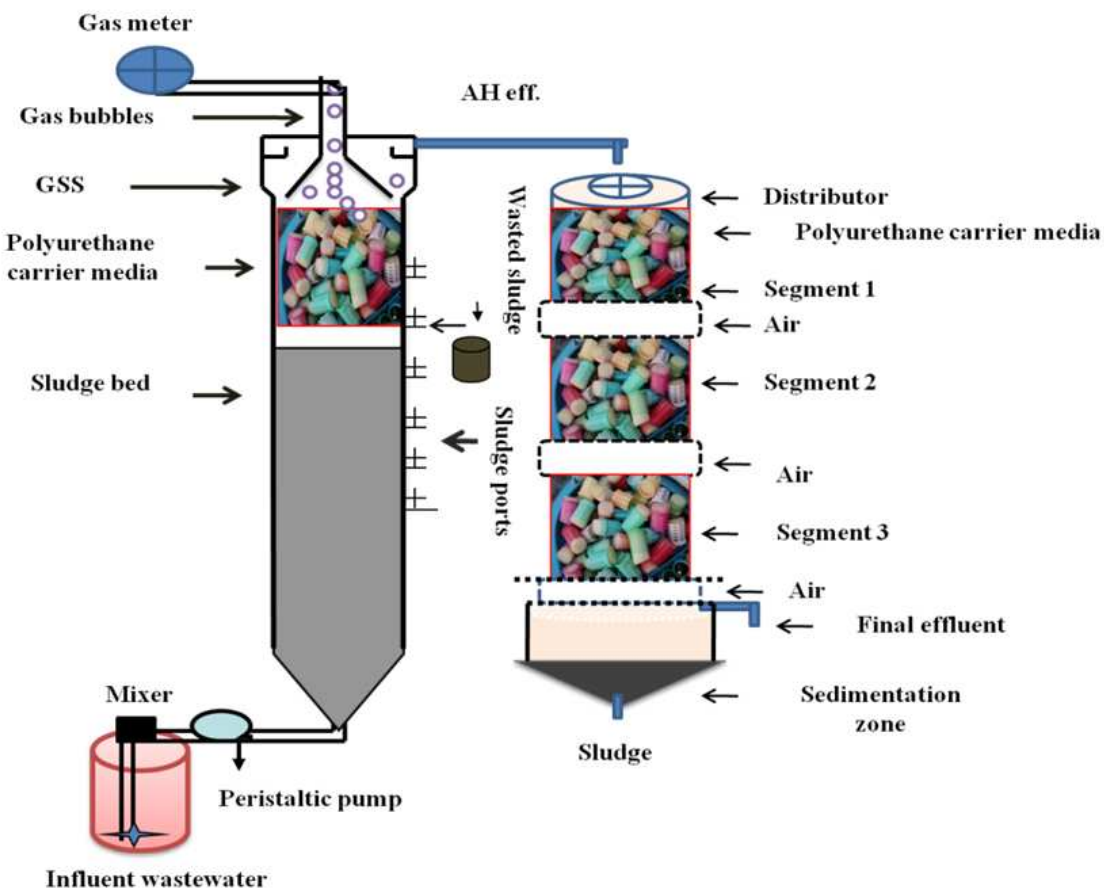


Figure 1. PTF module coupled with AH reactor for treatment of tomato industry wastewater

2.3. Polyurethane trickling filter (PTF) reactor

The PTF is packed with porous polyurethane foam (pore size= 0.63 mm) with relatively high specific surface area (256 m^2/m^3) to increase both the biofilm mass content and the removal efficiency of the reactor. The PTF module used in this study, consisted of three segments connected vertically in series. The polyurethane represents 15% of the total reactor volume (23l) (Fig. 1). Polyurethane media was warped with perforated polypropylene material (0.5 cm) to avoid clogging of the media and facilitate the air penetration inside the packing material. The PTF was equipped with 276 pieces each 40 mm height and 20 mm in diameter with 90% of porosity. The reactor was operated without inoculums. The distributer is situated on the top of the reactor and operated at 18 rpm for equal distribution of wastewater over the packing material. The air was naturally diffused to the reactor via three windows along the reactor height. There is no need for aeration as well as no backwashing.

2.4. Operating conditions

The operational conditions of the combined AH–PTF are shown in Table 1. Both reactors were operated for 330 days, 30–83; 134–212; and 234–324 days at HRTs of, respectively 14.5, 10 and 7.2 h. The first 30 days of operation were considered as a start-up period, while the periods from day 83 to 134 and from 212 to 234 were considered as acclimatization periods to the new HRT.

Operational conditions/ reactors	Run 1		Run 2		Run 3	
	HRT (h)	OLR ($kgCOD/m^3.d$)	HRT (h)	OLR ($kgCOD/m^3.d$)	HRT (h)	OLR ($kgCOD/m^3.d$)
AHreactor	8.6	2.8	6	3.5	4.3	4.5
PTF reactor	5.9	1.0	4	1.43	2.9	3

Table 1. Operational conditions of AH reactor in combination with PTF for the treatment of tomato industry wastewater

2.5. Analytical methods

Composite samples of the influent wastewater and the treated effluents were biweekly analyzed. COD, TSS, volatile suspended solids (VSS), total Kjeldahl nitrogen (TKj-N), ammonia (NH_4-N), nitrite (NO_2-N), nitrate (NO_3-N) and protein were analyzed according to standard methods (APHA, 2005). Raw wastewater samples were used for COD_{total}, 0.45 μm membrane-filtered samples for $COD_{soluble}$. The $COD_{particulate}$ was calculated by the differences between COD_{total} and $COD_{soluble}$, respectively. Biogas composition was measured using a gas chromatograph fitted with a thermal conductivity detector (TCD) and Poropak Q stainless steel column. The oven, injector, and detector temperatures were set as 40, 60 and 60 °C, respectively and hydrogen was used as the carrier gas. The instrument was calibrated using a mixture of 50% methane and 50% carbon dioxide. Volatile fatty acid (VFA) concentration was measured after centrifuging the samples to remove the suspended solids. A gas-liquid chromatograph equipped with a Flame Ionization Detector (FID) and Chromasorb 101 column was used for the analysis of VFA. The detector, injector and oven temperature were 200, 195 and 180 °C, respectively. The carrier gas used was nitrogen, and a mixture of hydrogen and air was used to sustain the flame in the detector.

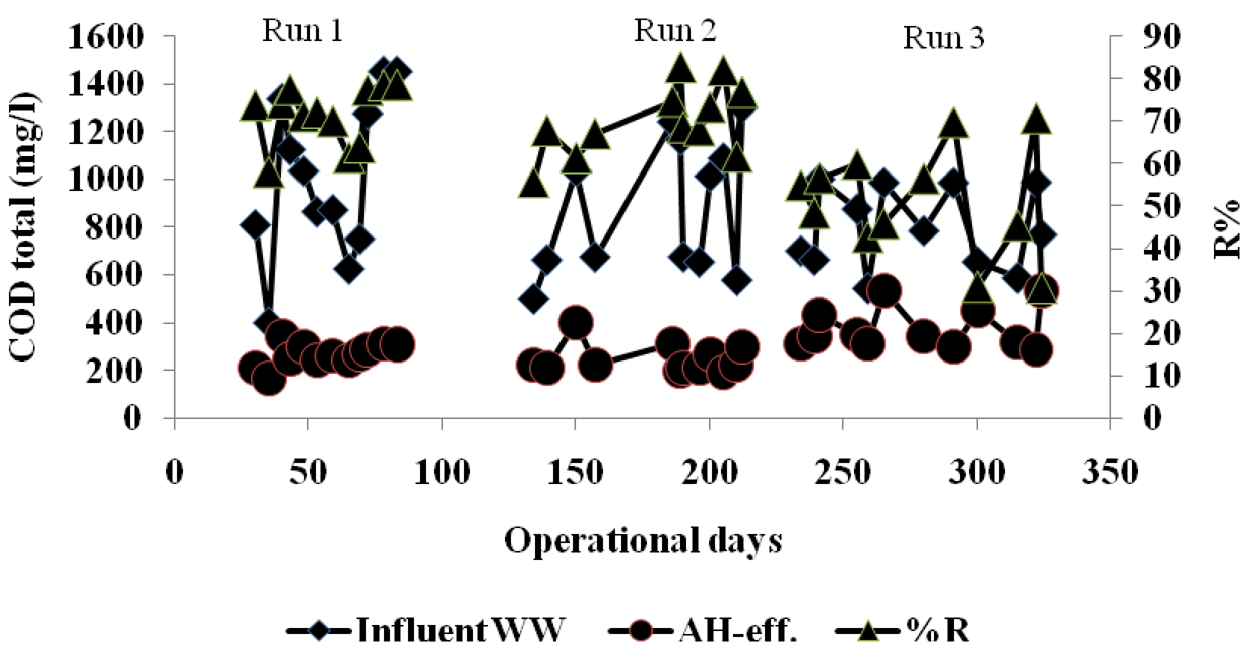
2.6. Scanning electron microscope (SEM)

The surface of sponge carriers and the attached microorganism species in the PTF reactor were analyzed by a JSM-5600 LV scanning electron microscope (JEOL, Japan). A sample of the microorganisms attached to the carriers was withdrawn from the PTF and placed in bottles. After drying for 10 h under vacuum at 40 °C, these samples were fixed in 0.1 mol/l phosphate buffer solution (pH 7.3) containing 2.5% glutaraldehyde for 12 h at 4 °C. After fixation, samples were rinsed three times in 0.1 mol/l of phosphate buffer solution (pH 7.3) and dehydrated gradually by successive immersions in ethanol solutions of increasing concentration (30, 50, 70, 80, 90, and 95%). The samples were then washed three times in 100% ethanol. The drying process was then completed by incubating the samples for 2 h at 40 °C. The sponge were then coated with gold powder and attached to the microscope support with silver glue. SEM photographs were taken at 25 and 20 kV.

3. Results and discussion

3.1. Efficiency of AH reactor as a pretreatment of tomato wastewater industry

Figs 2a, b and c show the effect of HRT on the percentage reduction of COD fractions (COD $_{total}$, COD $_{particulate}$ and COD $_{soluble}$). By increasing the HRT from 4.3 to 8.6 h, the COD_{total} of the effluent significantly reduced from 377±88 to 267±48 mg/l, and the removal efficiency of COD_{total} substantially increased from 51±12 to 71±7%. However, the residual values of COD_{total} in the treated effluent of the AH reactor remained unaffected by increasing the HRT from 6.0 to 8.6 h. Likely, the results in Fig. 2b show that the effluent quality of $COD_{soluble}$ and removal efficiency was maintained at the same level of 117 ±11mg/l and 64±9% respectively by decreasing the HRT from 8.6 to 6 h. This indicates that the AH reactor was operated under substrate limiting conditions at an HRT of 8.6 h. Accordingly it is recommended to apply such a system at OLR 3.5 kgCOD/m^3. d and HRT not exceeding 6.0 h. An increase in the HRT would result in a decrease in the wastewater linear velocity through the support material, improving the mass transfer from the liquid phase to the biomass and, therefore, favoring the process performance (Elmitwalli et al., 2000).



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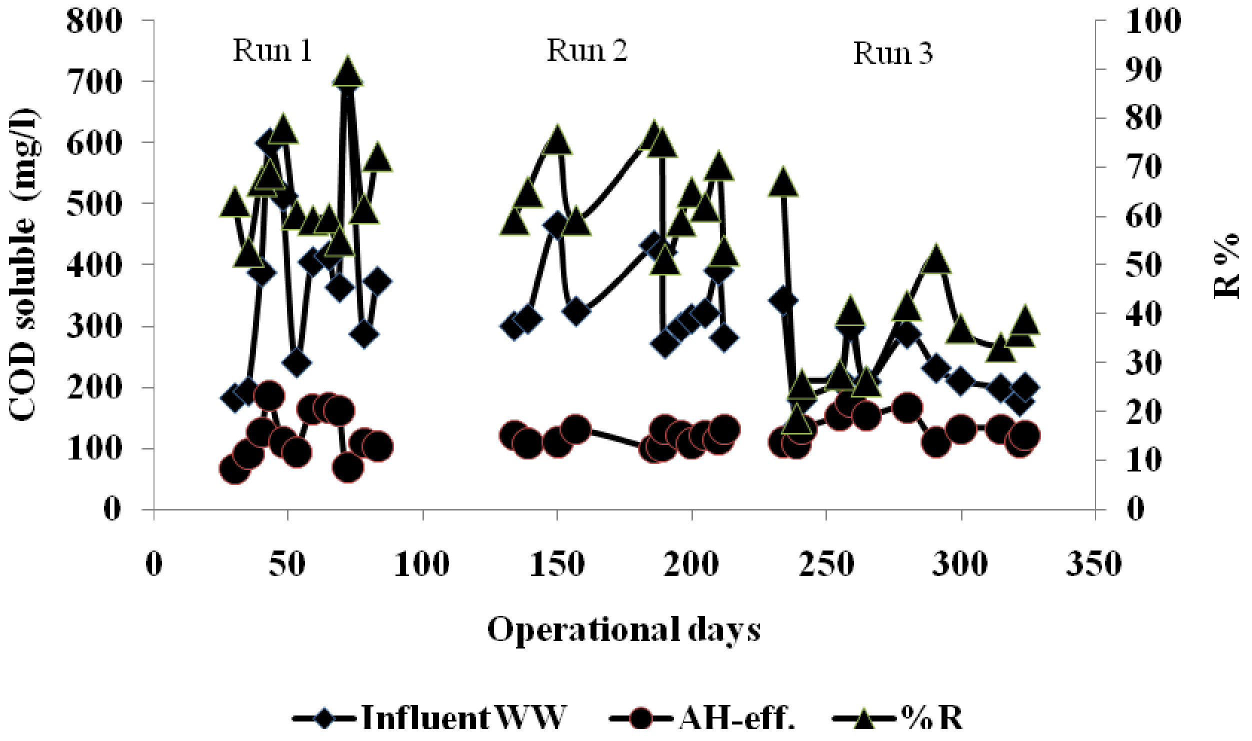

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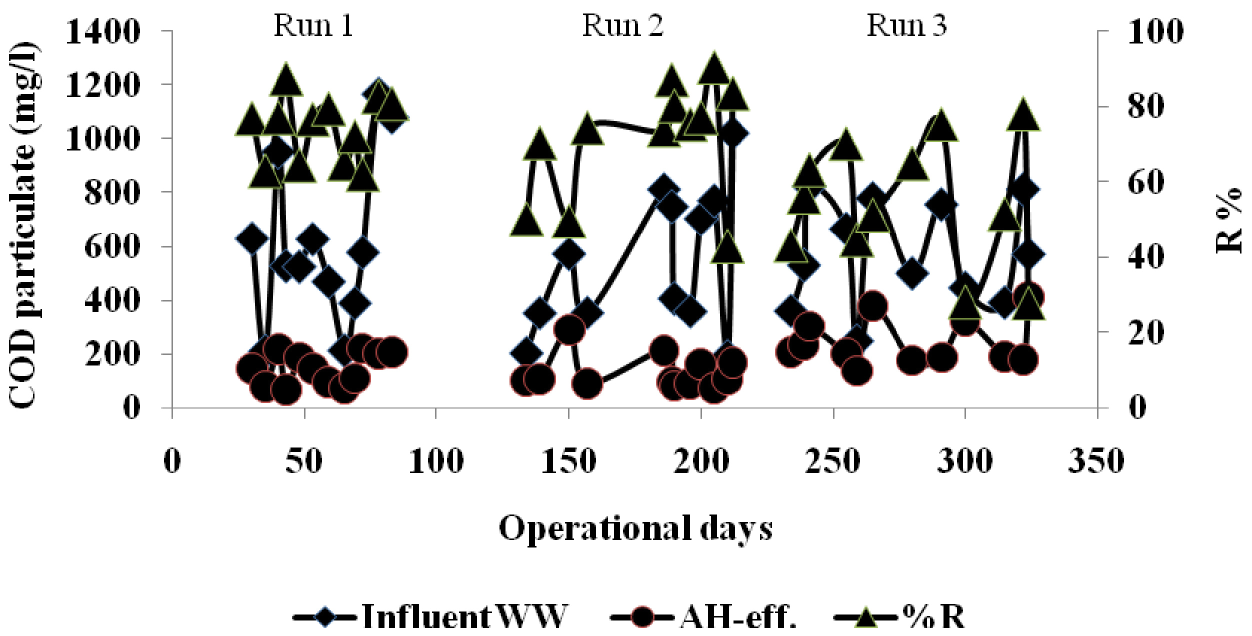


(c)

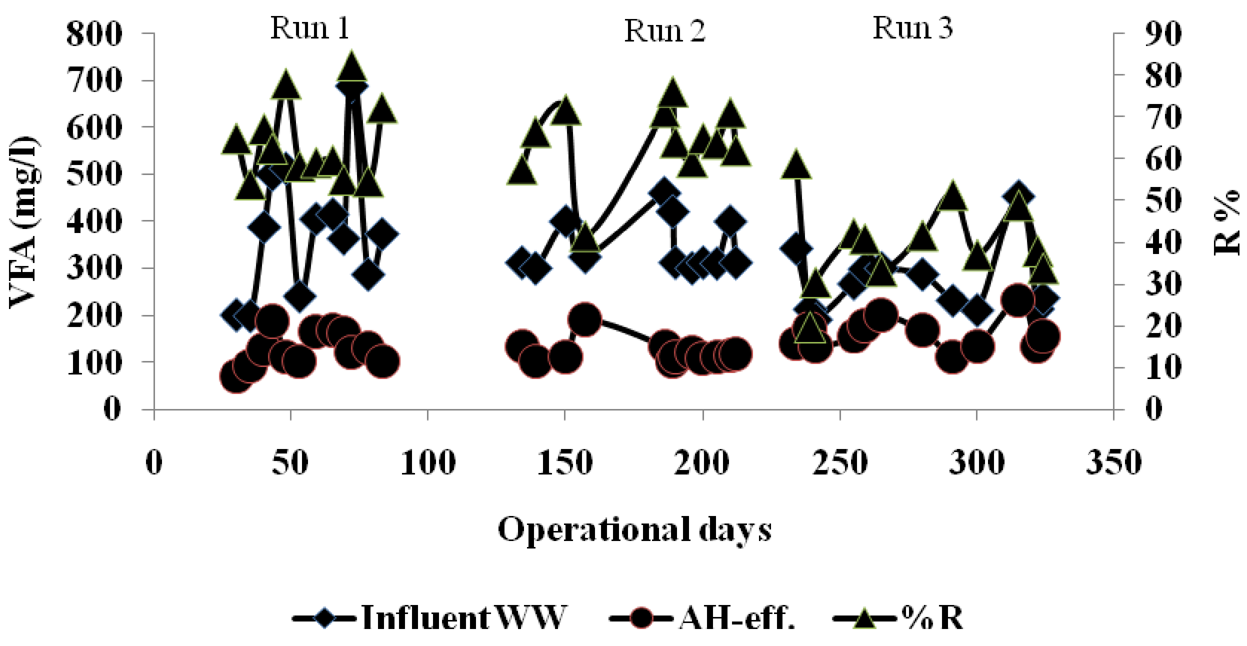
Figure 2. (a) COD $_{total}$ removal efficiency in an AH reactor treating Tomato industry wastewater at different HRTs ; (b) COD $_{soluble}$ removal efficiency in an AH reactor treating Tomato industry wastewater at different HRTs; (c) COD $_{particulate}$ removal efficiency in an AH reactor treating Tomato industry wastewater at different HRTs

The removal efficiency of COD_{total} in an AH reactor at an HRT of 4.3 h was higher than those obtained by Demirer and Chen, (2005) who used AH reactor for treatment of dairy wastewater at longer HRT of 15 days.Also, Gu¨ngo¨r and Demirer, (2004) achieved a lower COD removal efficiency of 37.9–50% in anaerobic batch reactor treating food industry wastewater.. The improved removal efficiency of COD_{total} in this study was mainly due to a higher removal efficiency of $COD_{particulate}$ as shown in Fig. 2c. In previous studies on opaque beer wastewater with UASB, 57% COD_{total} reduction was achieved at HRT of 24 h (Parawira et al., 2005). Similarly, studies of Cronin and Lo (1998) and Driessen and Vereijken (2003) on UASB with brewery wastewater showed that the COD_{total} reduction of 75–80% with the HRT in the range of 12–36 h. In the present study AH reactor could be optimally operated at an OLR of 3.5 kg COD/m^3.d and HRT not exceeding 6 h with COD_{total} reduction of 71% and methane yield of 0.48 m^3 CH_4/kg COD_{total} reduced. This high efficiency of AH reactor as compared to UASB reactor can be due to the presence of polyurethane carrier material in the sedimentation part which overcome sludge washout and improve the biodegradation process. Moreover,polyurethane carriers provide a much larger surface area for the attachment of biofilm which then leads to an increase of anaerobic biodegradation process.

Variations of VFAs in the influent and effluent of AH reactor are shown in Fig. 3a. Although, there was a significant fluctuation in the VFAs of the feed between 198 and 689 mg/l, the AH reactor showed that VFAs in the feed was effectively utilized by methanogenesis bacteria. VFAs in the effluent was quite low (below 121±23 mg/l) at HRTs of 8.3 and 6 h.However, the residual values of VFAs in the treated effluent was increased at decreasing the HRT(4.3 h) as shown in Fig.3a). Apparently, this can be attributed to limited activity of methanogens in the reactor under these operating conditions. Likely, Amit et al., (2007), found that the VFAs concentration increased in the treated effluent of AH reactor treating industrial cluster wastewater, when the HRT reduced from 12 to 4 h.

The variations of biogas production at different HRTs are shown in Fig. 3b. The biogas production was low (2.6 l/d) at an HRT of 4.3 h. HRT was prolonged up to 6 and 8.3 h and the gas production reached as high as 4.0 l/d, equivalent to 0.48 m^3/ kg COD removed. d. Similarly, Oscar et al., (2008) found that the value of methane yield in an AH treating food industry wastewater increased from 0.07 to 0.18 l CH_4/g COD added when the HRT increased from 1.0 to 5.5 days. The average methane yield in the gas composition was 67% as shown in Fig.3b.

AH reactor was found to be very effective for removal of TSS and VSS as shown in Figs 4a and b. TSS and VSS removal efficiencies increased from 57 ±10 to 70±8 % and from 70±8 to 78±4 % when the HRT rose from 4.3 to 6 h and from 6 to 8.3 h., respectively. The results obtained demonstrate that clogging of the support polyurethane media in the AH reactor was not evident in spite of the high concentration of TSS contained in the influent (Fig.4a). A previous study (Vartak et al., 1997) reported VSS removal efficiencies of up to 91% in up-flow anaerobic attached film reactors with a combination of limestone and polyester as support media treating diluted dairy wastewaters but operating at a longer HRT of 33 d. Lower VSS removal efficiencies (66%) have been achieved in an anaerobic baffled reactor (ABR) fed with dairy wastewater at a HRT of 5 d. (Chen and Shyu, 1996).



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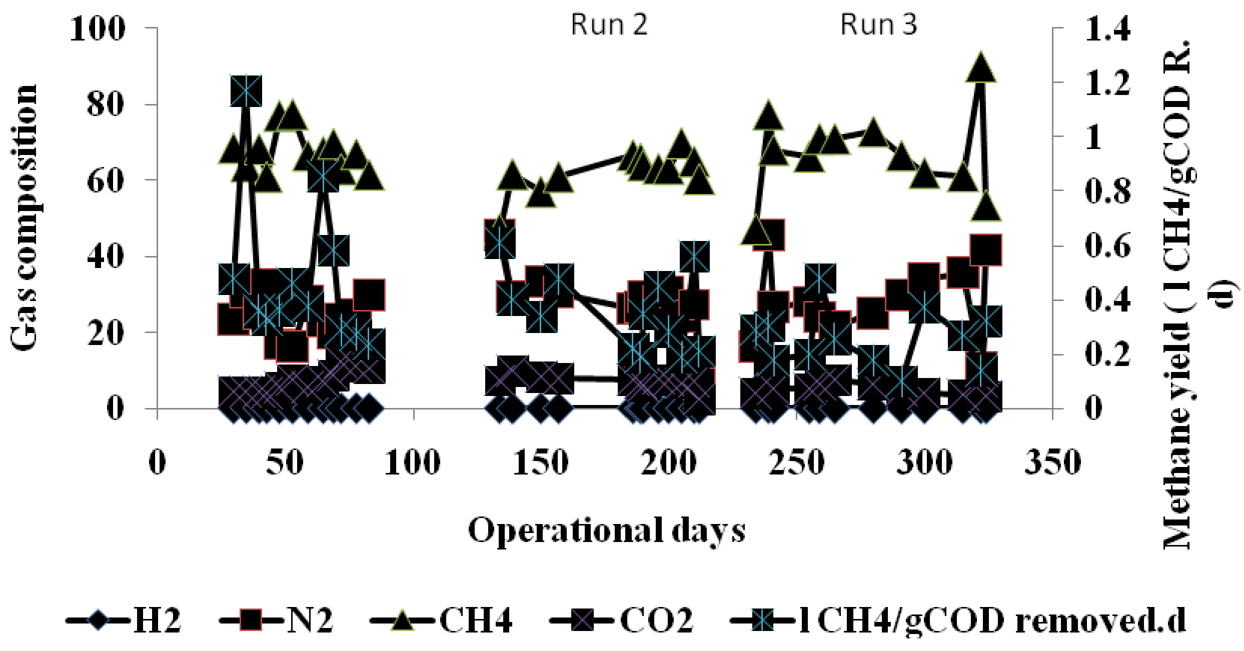
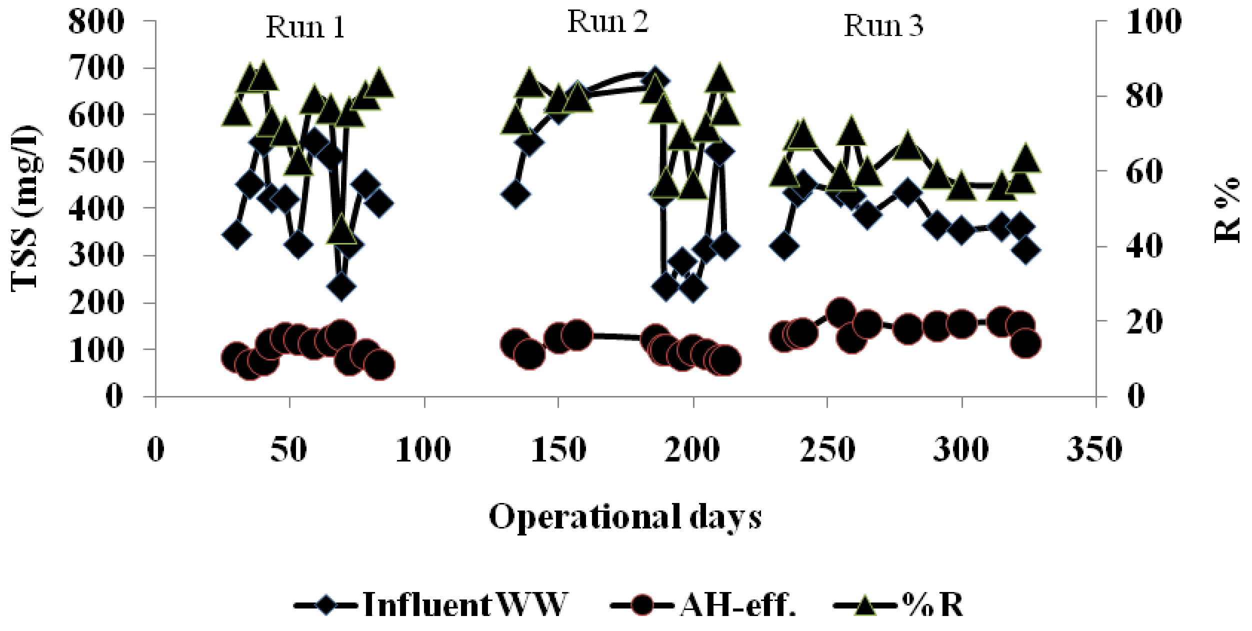


(b)

Figure 3. (a) VFAs removal efficiency in an AH reactor treating Tomato industry wastewater at different HRTs; (b) Biogas production and gas composition in an AH reactor treating Tomato industry wastewater at different HRTs



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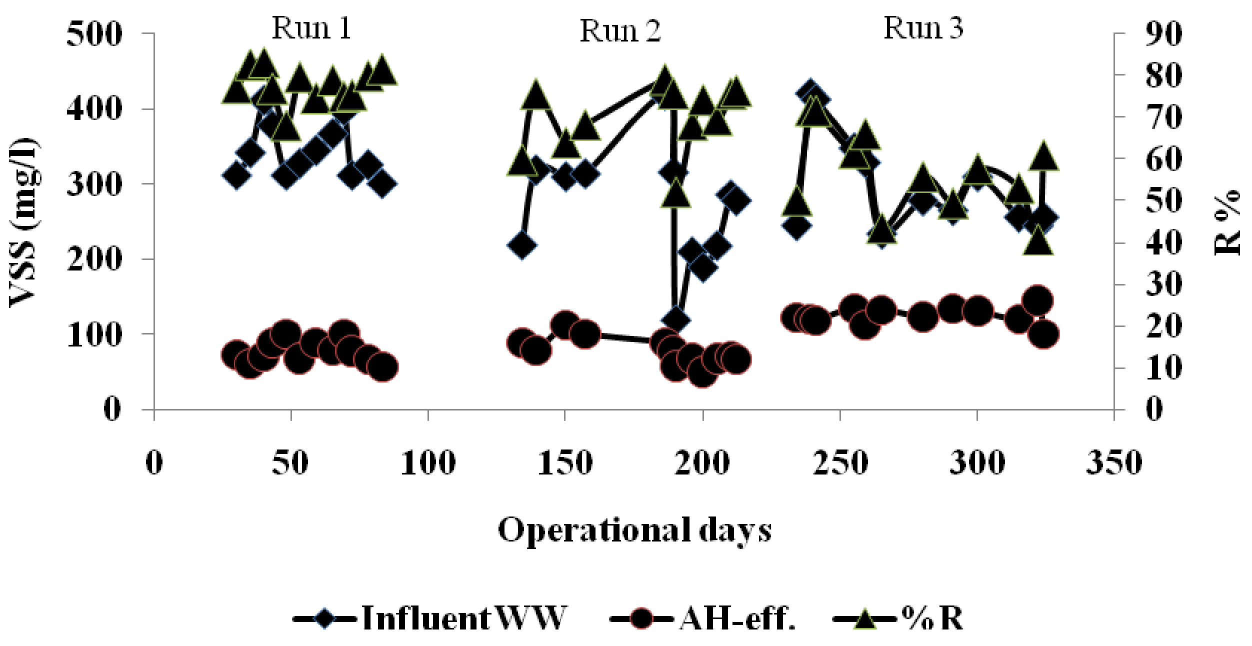


(b)

Figure 4. (a) TSS removal efficiency in an AH reactor treating Tomato industry wastewater at different HRTs ; (b) VSS removal efficiency in an AHreactor treating Tomato industry wastewater at different HRTs

No significant difference was found in the removal of protein in the AH reactor between different HRTs as shown in Fig. 5. The maximum conversion of protein was achieved and accounted for 19.8±8.5% at an HRT of 4.3 h of the protein content. The conversion of protein dropped at an HRT of 8.6 and 6 h (14±5%). The drop in protein hydrolysis might be due to chemical precipitation of NH_4-N (Miron et al., 2000).

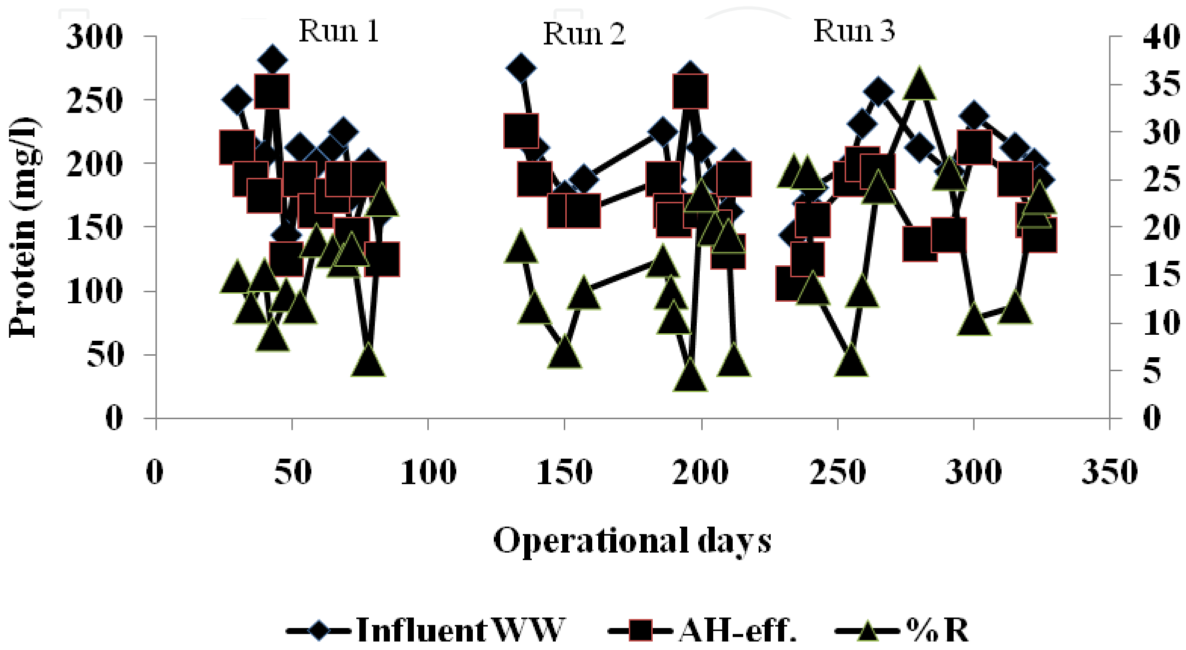
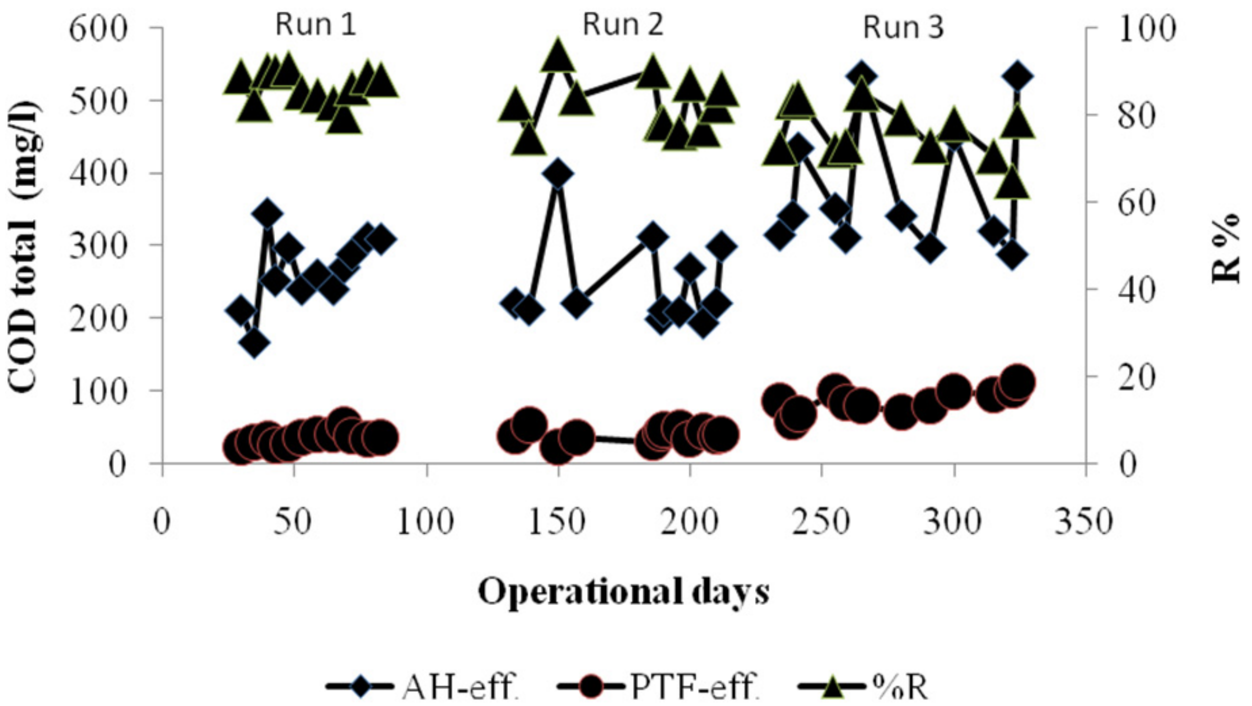


Figure 5. Protein removal efficiency in an AH reactor treating Tomato industry wastewater at different HRTs

3.2. Polyurethane trickling filter (PTF) as a post-treatment system

The results presented in Figs. 6a, b and c show the effect of OLR on the removal efficiency of the different COD fractions (COD_{total}, $COD_{soluble}$ and $COD_{particulate}$) in the PTF system treating AH reactor effluent. The results reveal a significantly improved COD_{total} removal at decreasing the OLR. The system provided a mean effluent quality of 35±9 mg/l for COD_{total} at an OLR of 1.0 kgCOD/m^3.d., which is significantly lower than that at an OLR of 3.0 kgCOD/m^3.d (86±16 mg/l). The improved removal efficiency of COD_{total} was mainly due to a higher removal efficiency of $COD_{soluble}$ and $COD_{particulate}$ (Figs. 6b and c). This excellent performance towards the removal of $COD_{soluble}$ and $COD_{particulate}$ matter can be attributed to entrapment or/and adsorption followed by hydrolysis and degradation in the polyurethane packing material. Low removal efficiency of COD_{total} at an OLR of 3 kgCOD/m^3.d can be explained by excess biofilm accumulation, filling in pores of the polyurethane packing material and reducing the mass transfer capabilities (Chen et al., 2006; Tawfik & Klapwijk, 2010) and DO concentration dropped from 5.2 to 3.2 mg/l in the PTF as the OLR increased from 1.0 to 3 kgCOD/m^3. d. However, the results presented in Fig. 6a show that the residual value of COD_{total} in the treated effluent of the PTF system remained unaffected by decreasing the OLR from 1.43 to 1.0 kgCOD/m^3.d, as a result of increasing the HRT from 4.0 to 5.9 h. Accordingly it is recommended to apply such a system at loading rate of 1.43

kgCOD/m³. d., and HRT not exceeding 4.0 h. The results obtained in this investigation were higher than those obtained by El-kamah et al., (2010 & 2011) who used down flow hanging sponge (DHS) system for post treatment of anaerobically pretreated onion industry wastewater. The system was operated at an OLR of 5.1 kgCOD/m³.d. and a similar HRT of 4.2 h. The system provided an effluent quality of 80 mg/l for COD and 30 mg/l for TSS.



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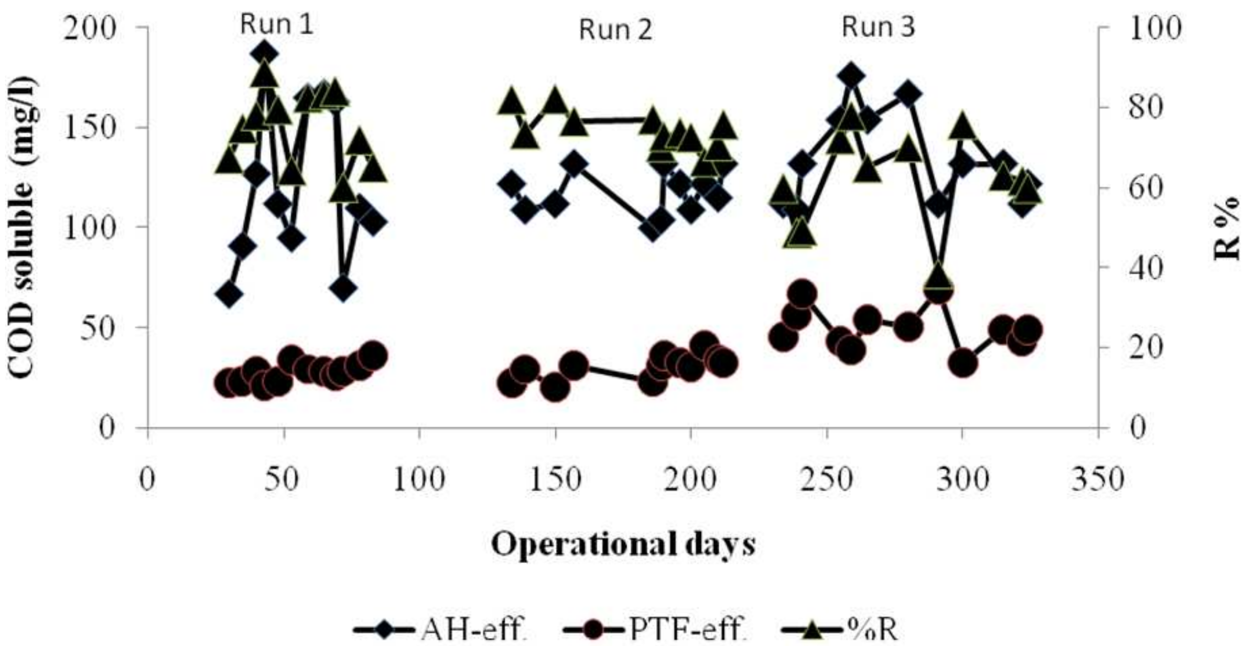

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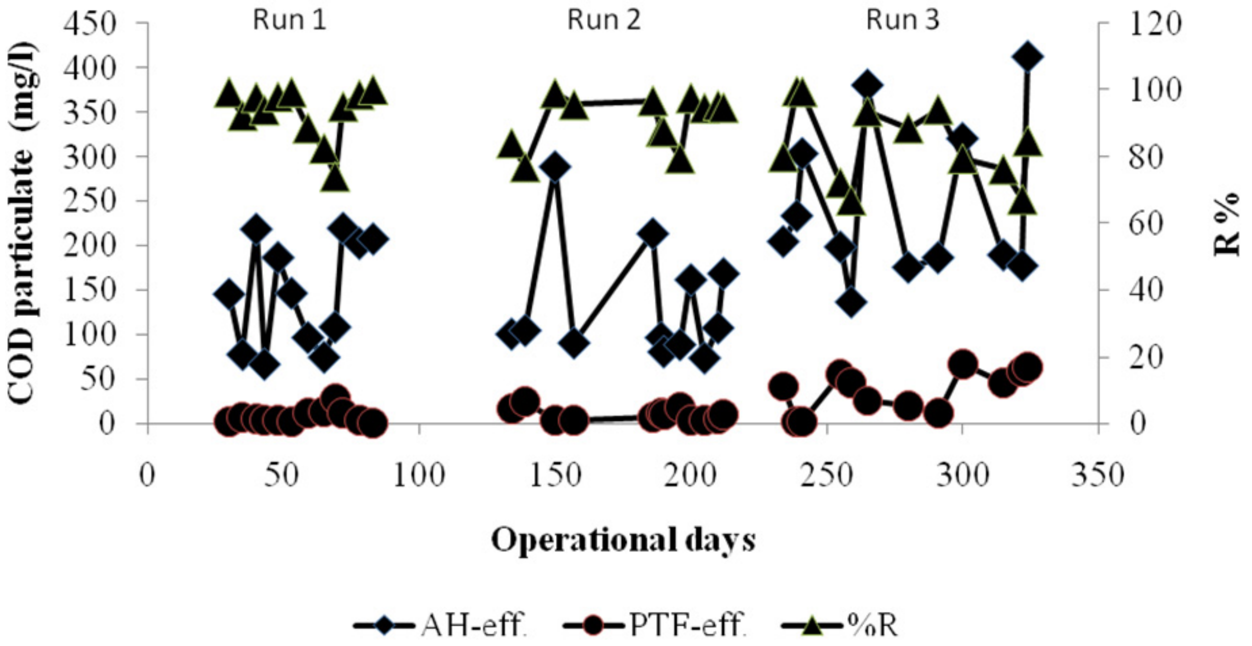

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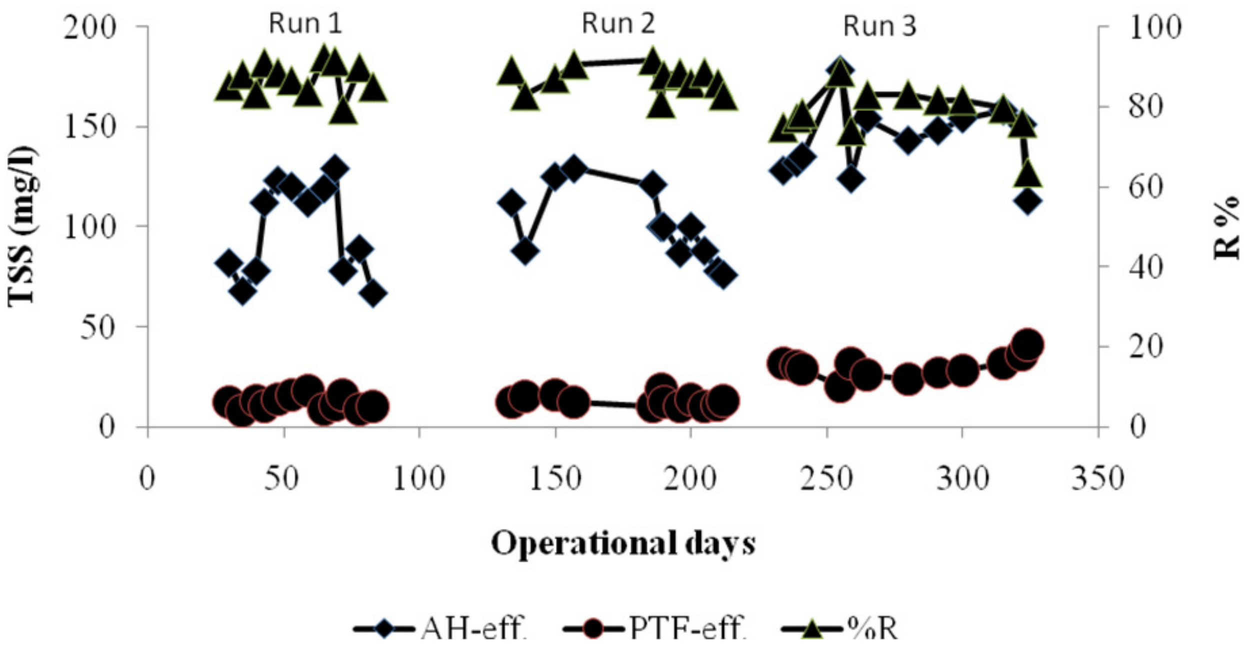
Figure 6. (a) The efficiency of PTF for removal of COD $_{total}$ at different OLRs; (b) The efficiency of PTF for removal of COD $_{soluble}$ at different OLRs; (c) The efficiency of PTF for removal of COD $_{particulate}$ at different OLRs

The results in Figs. 7a and b revealed that the removal efficiencies of TSS and VSS in the PTF reactor significantly decreased at increasing the OLR from 1.43 to 3.0 kgCOD/m^3.d., while decreasing the OLR from 1.43 to 1.0 kgCOD/m^3.d did not affect seriously on the removal efficiencies. The reactor achieved removal efficiencies of 87.1; 87 and 78.6% for TSS and 89.3; 88.5 and 79.5 % for VSS at OLRs of 1,1.43 and 3.0 kgCOD/m^3.d. respectively. This high removal efficiency for coarse suspended solids in PTF reactor were mainly due to the high entrapment capacity, high specific surface area and porosity of the polyurethane packing material. Tawfik &klapwijk, (2010) found that polyurethane is better than polystyrene packing media for removal of TSS and VSS.

The nitrification efficiency in the PTF treating AH reactor effluent at different OLRs is shown in Fig. 8a. The results show that increasing the OLR from 1.0 to 1.43 and from 1.43 to 3.0 kg COD/m^3.d, results in an increase of the ammonia concentration in the final effluent from 2.7±1.3 to 2.8±1.3 mg/l and from 2.8±1.3 to 17.8±3.7 mg/l, respectively. At OLR of 1.1, 1.43, and 3.0 kg COD/ m^3.d, ammonia was removed by values of 89.4±5.9%, 89.7±4.6 % and 25 ±10 %, while at the same time 17.7 ±3.5, 17±4.4 and 1.7±0.9 mg/l of nitrate were, respectively produced as shown in Fig. 8a. Based on these results, it can be concluded that the OLR imposed to the PTF reactor should remain below 3 kg COD/m^3.d to achieve a high nitrification efficiency as also found by El-kamah et al., (2011) for down flow hanging sponge (DHS) system treating anaerobically pretreated onion industry wastewater.



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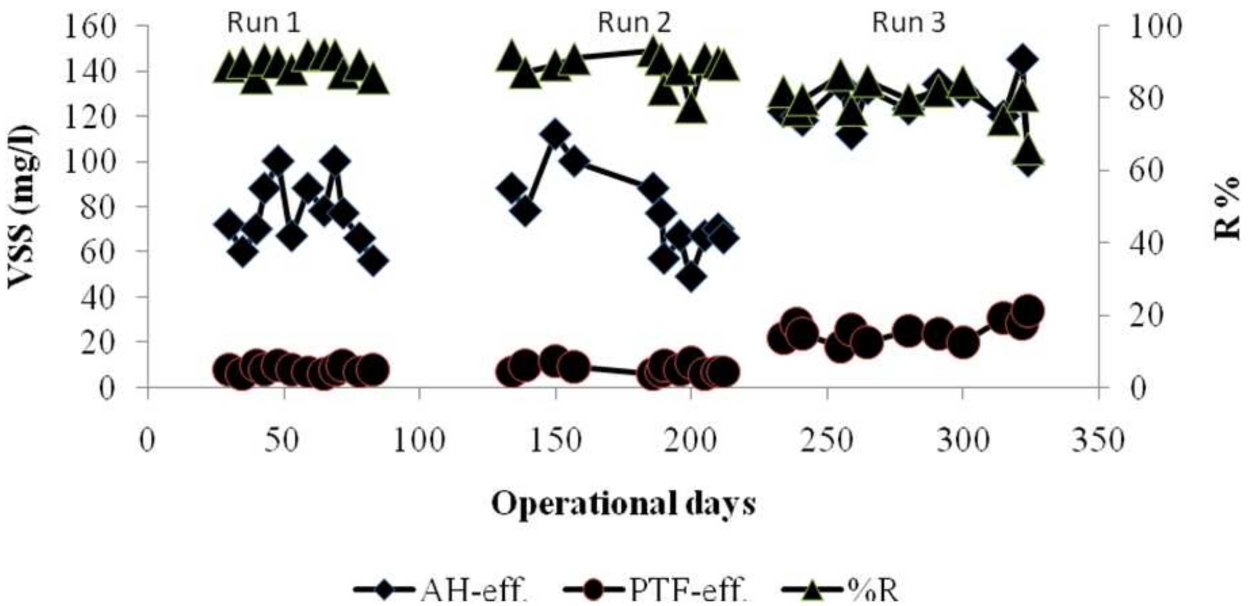

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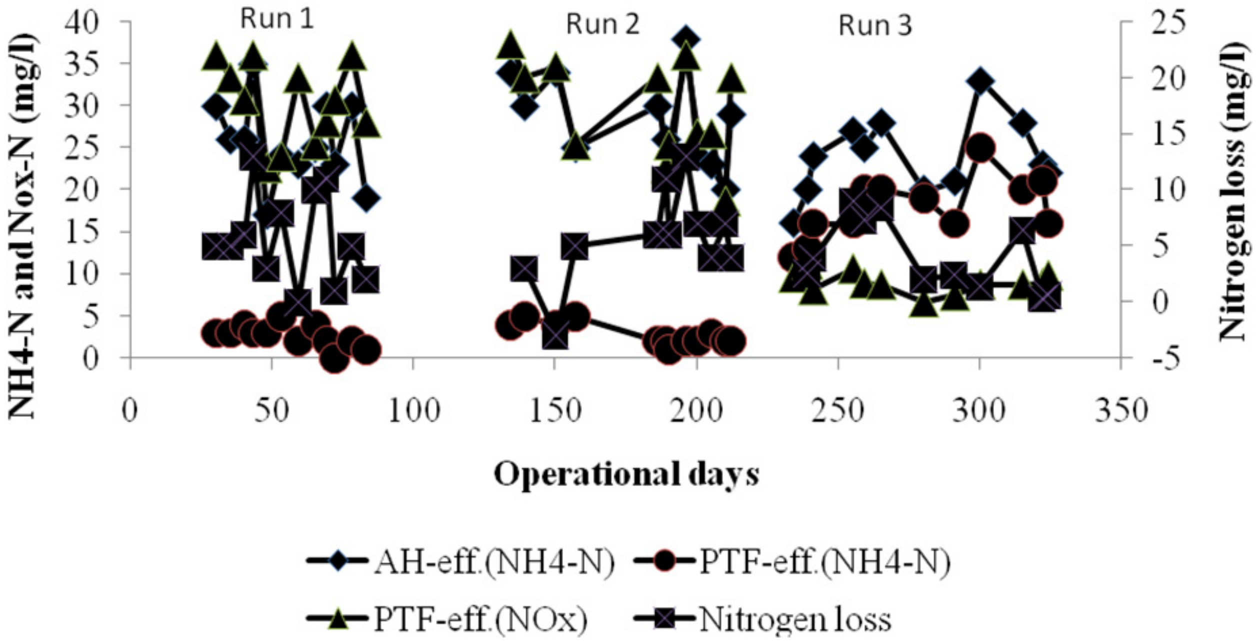
Figure 7. (a) The efficiency of PTF for removal of TSS different OLRs; (b) The efficiency of PTF for removal of VSS at different OLRs



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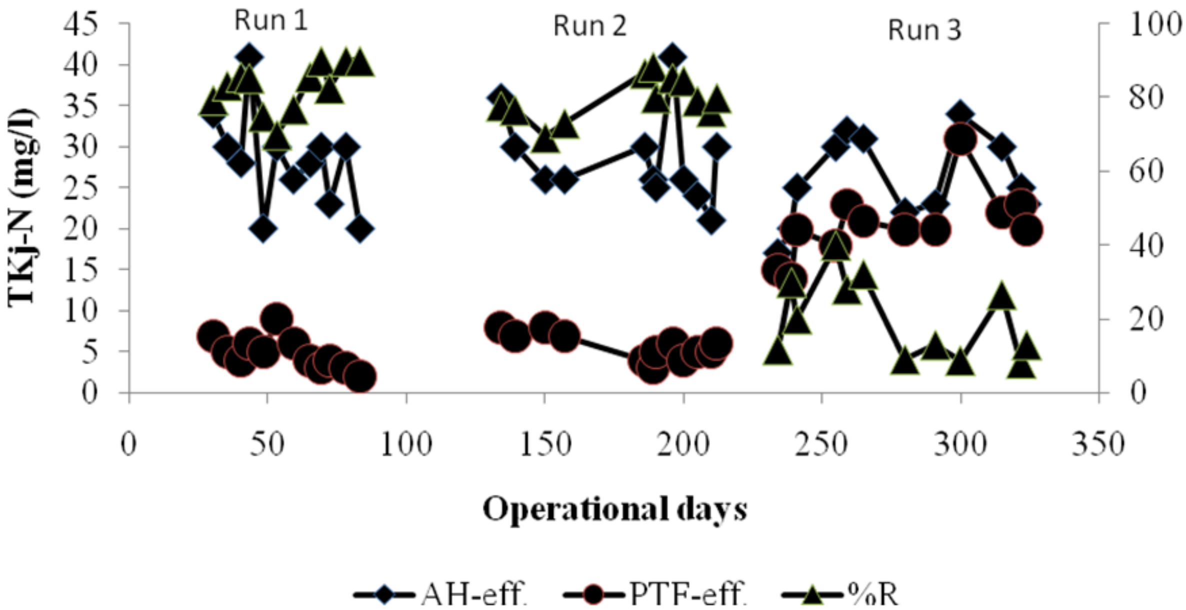


(b)

Figure 8. (a) Nitrification efficiency and total nitrogen removal in PTF at different OLRs; (b) The efficiency of PTF for removal of TKj-N at different HRTs and OLRs

The results revealed that the nitrification rate in PTF was strongly dependant on VSS/ TN ratio. A low nitrification rate was achieved in the PTF at the high influent VSS/TN ratio of 5±1, the nitrification rate was 0.013 kg NO_x-N/m^3.d as compared to VSS/N ratio of 2.8, the nitrification rate amounted to 0.1 kgNO_x-N/m^3.d. This can be attributed to the attachment and degradation of volatile suspended solids on the surface of the nitrifying biofilm where they take away oxygen which otherwise would have been available for nitrifiers (Tawfik et al., 2010). The TKj-N removal in the PTF treating AH reactor effluent was 82.8 ±6.4% at an OLR of 1.0 and 1.43 kg COD/m^3.d as compared to 20 ±10% at higher OLR of 3.0 kg COD/m^3.d (Fig. 8b). The nitrogen loss amounted to 20% (Fig. 8a) which can be due to (1) assimilation of biomass (2) denitrification occurring in the anoxic zone of the biofilm (Holman & Wareham, 2005).

3.3. Profile of polyurethane trickling filter (PTF) reactor

Profile of dissolved oxygen (DO) concentration along the height of PTF shows a gradual increase in the concentration of DO as the wastewater flows down. DO in the final effluent was in the range of 4-4.6 mg/l as shown in Fig.9a. The profile results of PTF showed that in the upper part of the PTF system, mainly COD was oxidized while nitrification was taken place in the lower part of the system, where nitrifiers are available. The results in Fig. 9 b,c and d show that most of the COD fractions (COD_{total}, $COD_{soluble}$ and $COD_{particulate}$) were removed in the 1st and 2nd segment of PTF reactor.

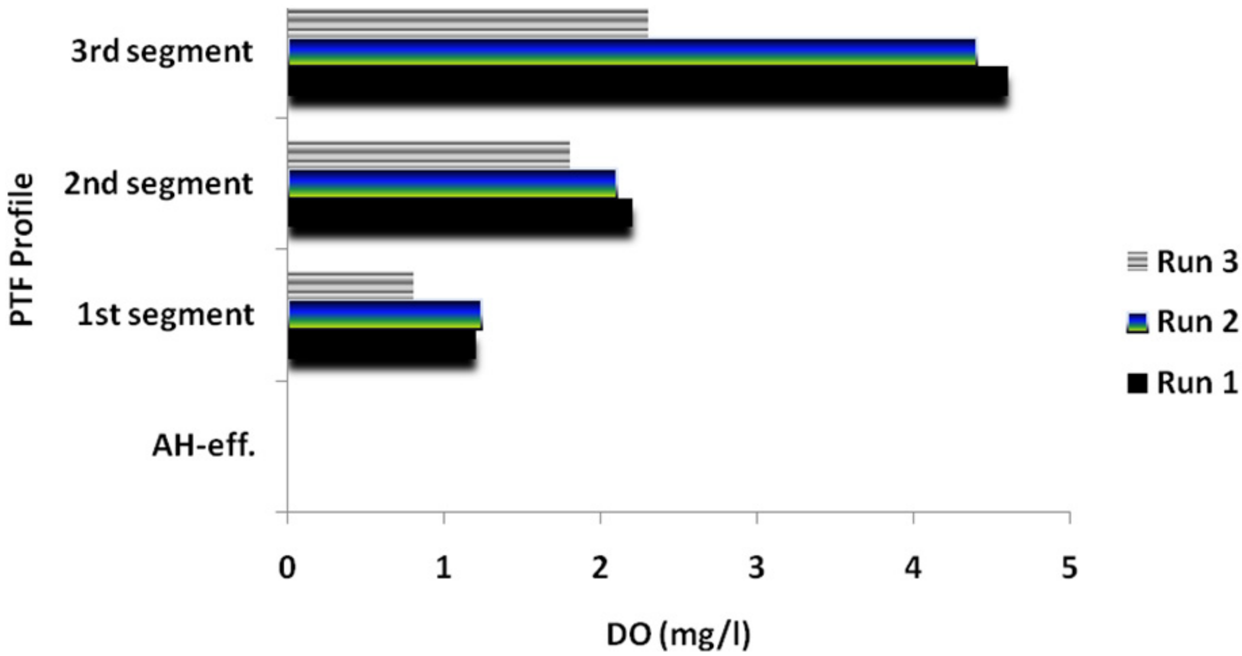
The 3rd segment provided a little additional removal of COD fractions as shown in Figs. 9 b, c and d. This can be explained by the fact that the most of the coarse and soluble organic matter were adsorbed and degraded in the segments 1 and 2. Likely TSS and VSS concentrations were gradually decreased from segment 1 to 3 as shown in Figs. 10 a and b. The results in Figs. 11a and b show that nitrification was very limited in the 1st segment of PTF system at OLR of 4.2 kg COD/m^3 .d. This was due to the presence of an insufficient ammonia oxidizer population at high loading rate as they cannot compete with heterotrophs for space and oxygen. In the 2nd and 3rd segment of PTF system, a high nitrification rate was achieved at lower OLRs of 2.1, and 1.4 kg COD/m^3 .d.

These results demonstrate that at OLR exceeding 4.2 kg COD/m^3 d heterotrophic bacteria still prevail in the 1st segment of PTF system, but the nitrifying bacteria promoted in the 2nd , and 3rd segment of PTF system when the OLR drops to 2.1 and 1.4 kg COD/m^3.d, respectively. The ammonia oxidation and TKj-N removal (Fig. 11a and c) was virtually approximately complete, only 1.7 mgNH_4-N/l and 4.0 mg TKj-N/l provided in the final effluent of PTF system.

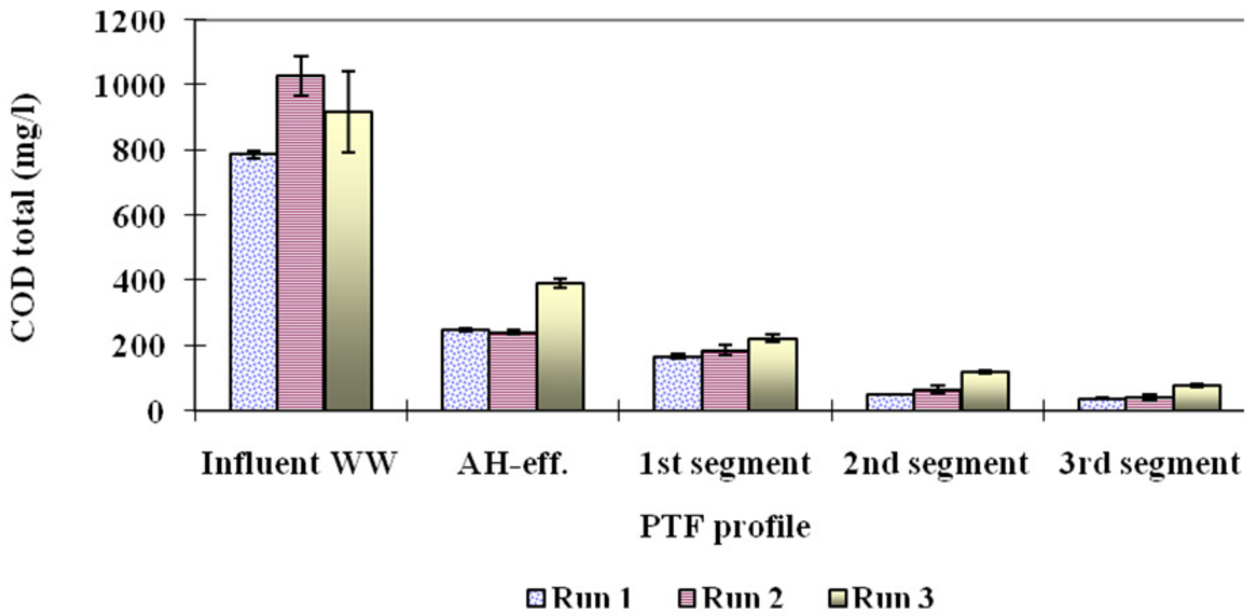
3.4. Efficiency of the combined system (AH+PTF) treating tomato industry wastewater at different OLRs and HRTs

The results presented in Table 2 revealed that decreasing the total HRT from 14 to 10 h was not significantly affected on the removal efficiency of COD fractions (COD_{total}, $COD_{soluble}$

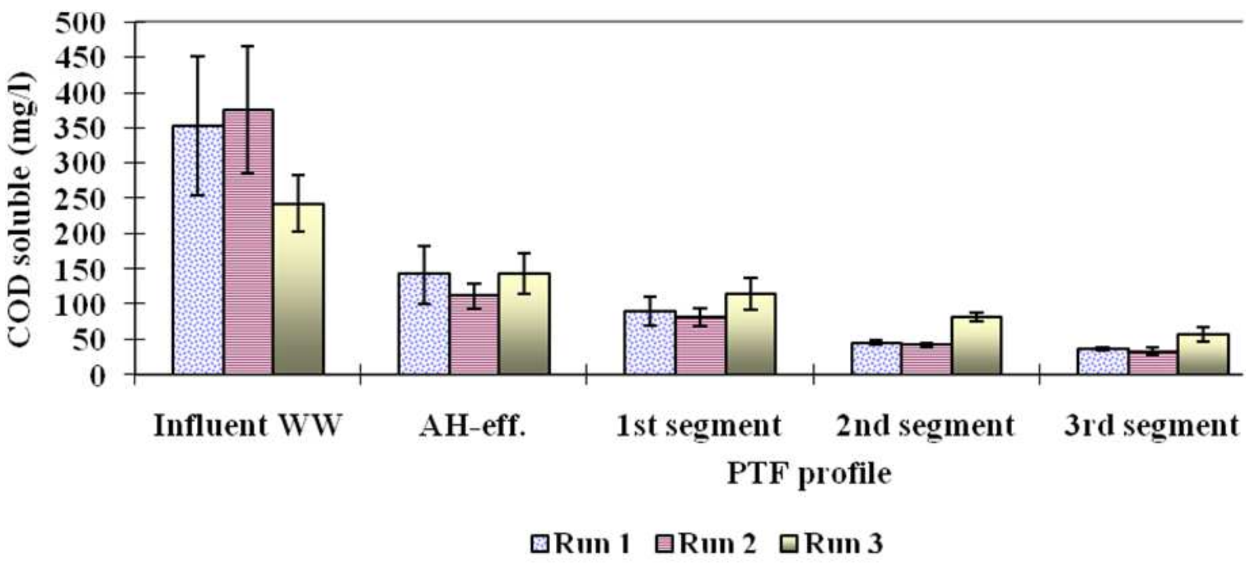
and COD particulate). However, decreasing the total HRT from 10 to 7.2 exerted a negative impact on the removal efficiency of the total process as shown in Table 2.



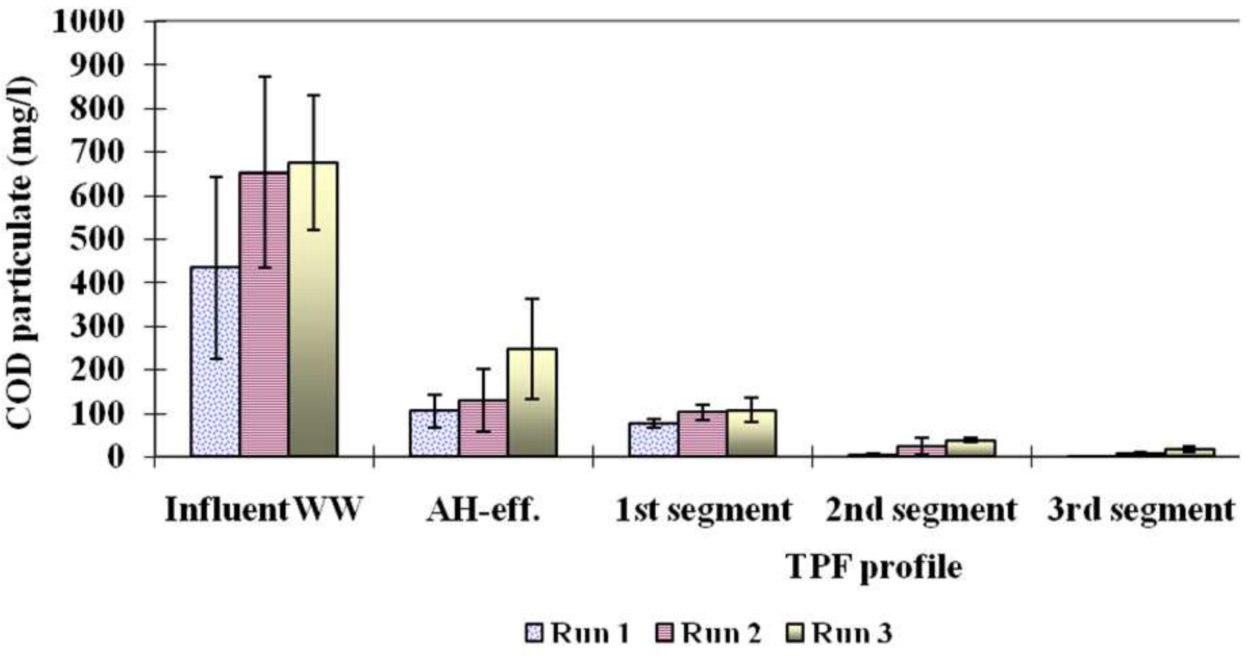
(a)



(b)

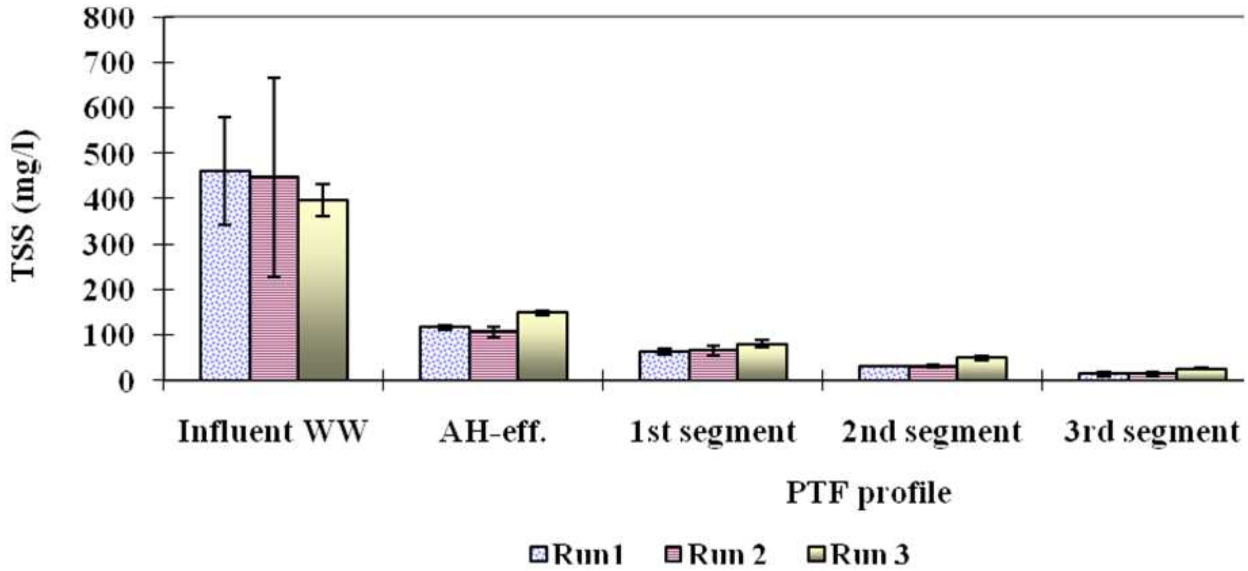


(c)

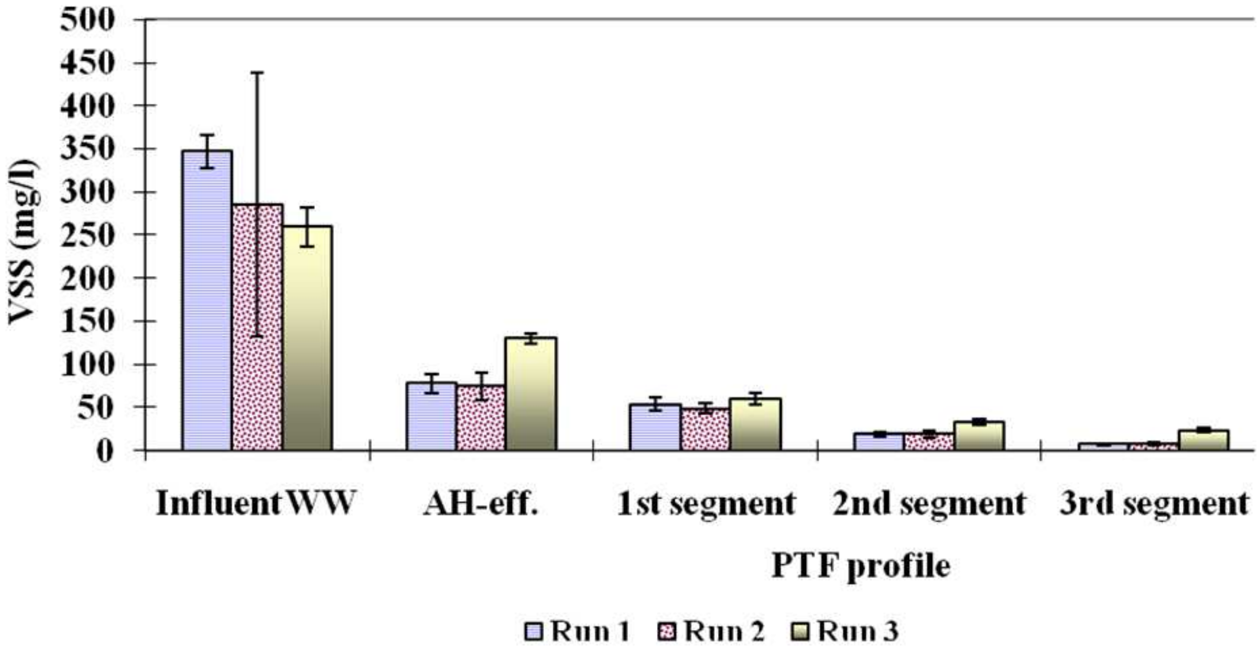


(d)

Figure 9. (a) DO concentration along the height of PTF reactor treating AH reactor effluent;
(b) COD $_{total}$ removal efficiency along the height of PTF reactor treating AH reactor effluent;
(c) COD $_{soluble}$ removal efficiency along the height of PTF reactor treating AH reactor effluent;
(d) COD $_{particulate}$ removal efficiency along the height of PTF reactor treating AH reactor effluent

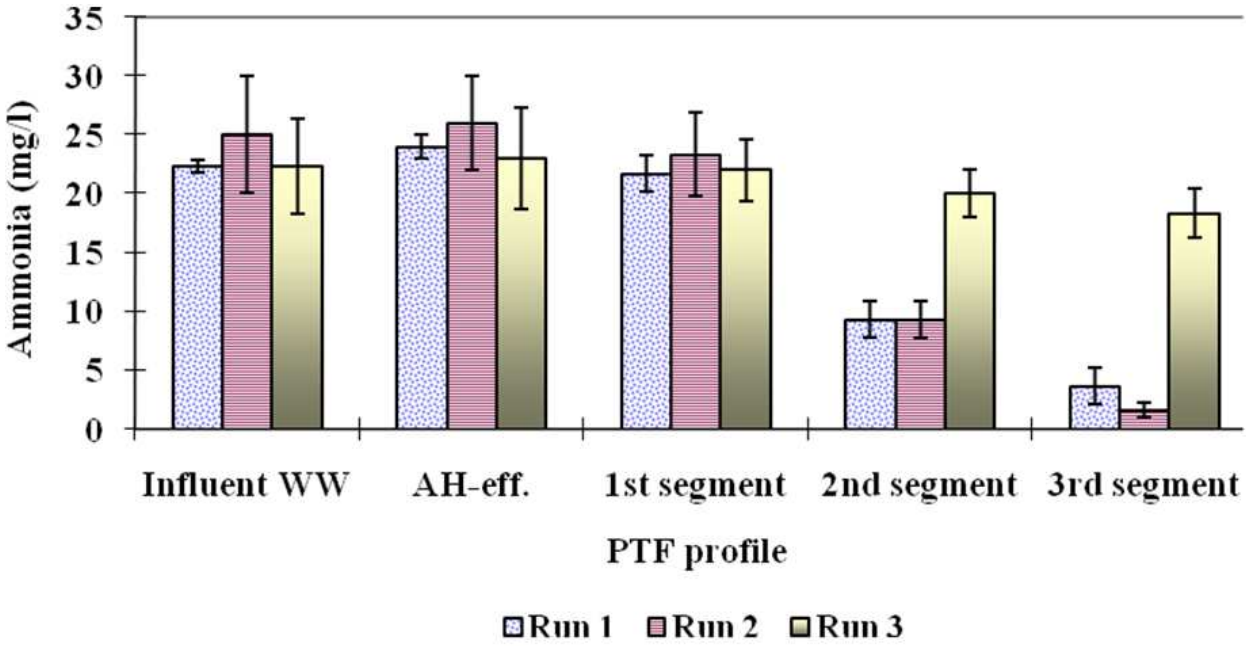


(a)

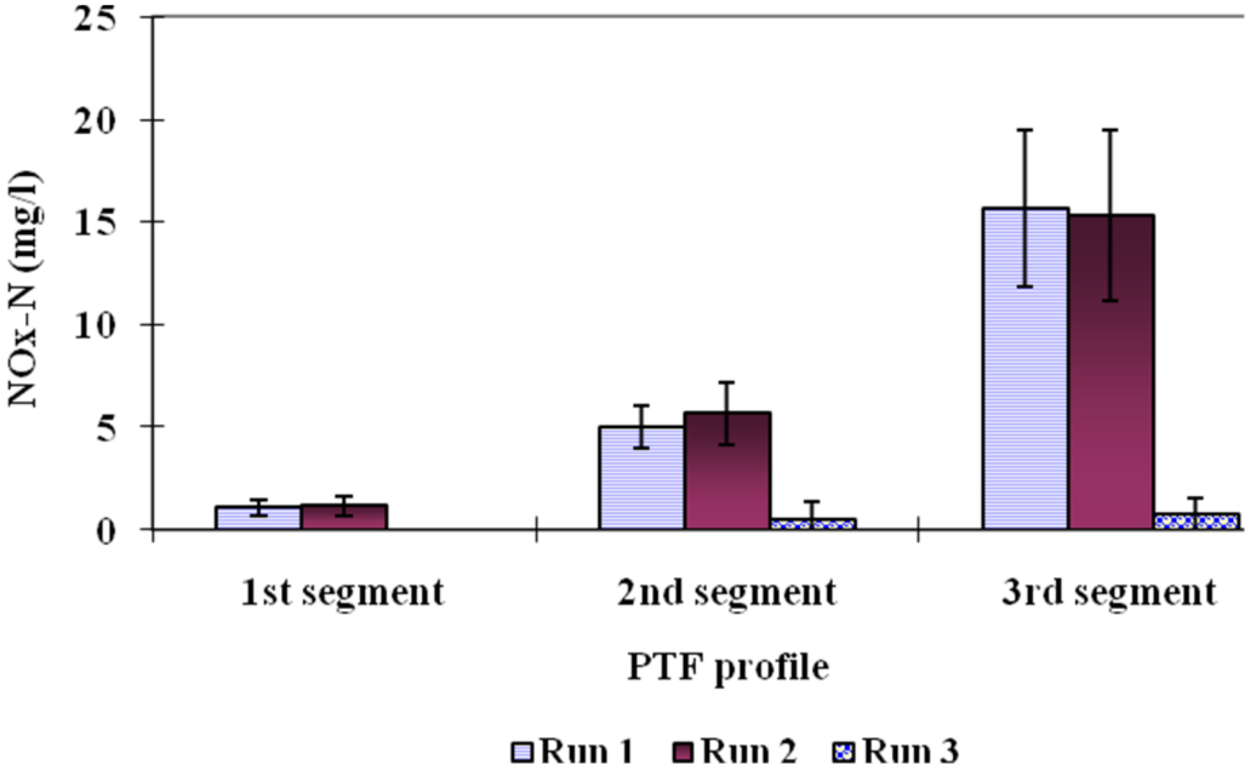


(b)

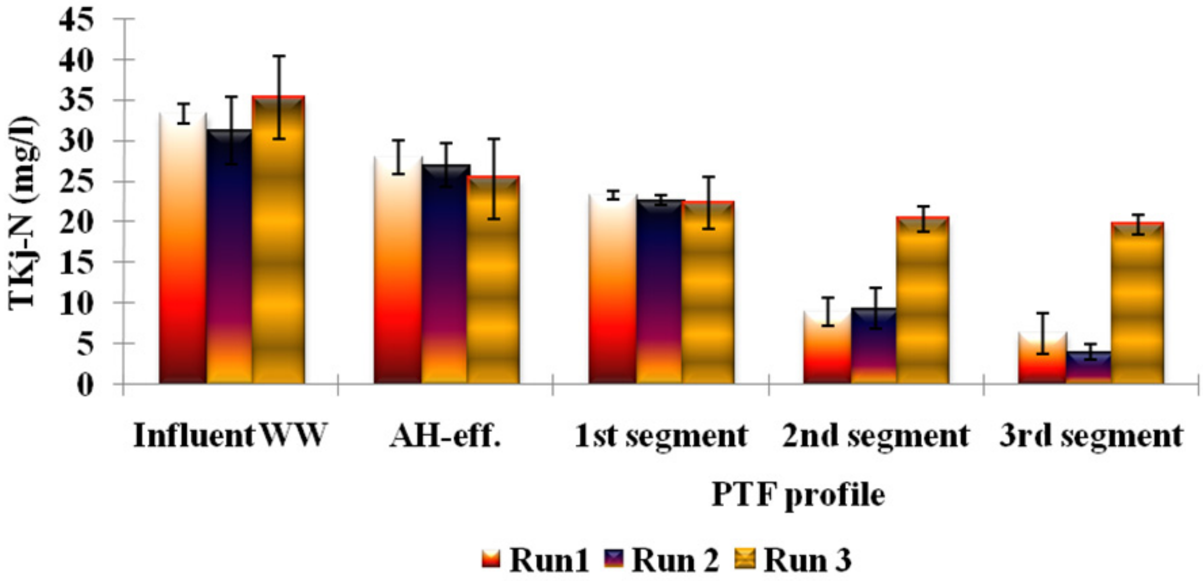
Figure 10. (a) TSS removal efficiency along the height of PTF reactor treating AH reactor effluent; (b) VSS removal efficiency along the height of PTF reactor treating AH reactor effluent


35
30
25
20
15
10
5
0
Ammonia (mg/l)
Influent WW
AH-eff.
1st segment
2nd segment
3rd segment
PTF profile
Run 1
Run 2
Run 3

(a)


25
20
15
10
5
0
NOx-N (mg/l)
1st segment
2nd segment
3rd segment
PTF profile
Run 1
Run 2
Run 3

(b)



(c)

Figure 11. (a) NH_4-N removal efficiency along the height of PTF reactor treating AH reactor effluent; (b) NOx –N production along the height of PTF reactor treating AH reactor effluent; (c) TKj-N removal efficiency along the height of PTF reactor treating AH reactor effluent

At a total HRT of 14 and 10 h, the combined system (AH+PTF) provided an overall removal efficiencies of 96±2% and 95±2.2% for COD_{total}, 92±3.5% and 91±3% for $COD_{soluble}$ and 98±2.4% and 97.4±2.6 for $COD_{particulate}$ respectively. The overall removal efficiency of COD fractions was dropped at a total HRT of 7.2 h., i.e. 88.7±3.3% for COD_{total}; 76±9.1% for $COD_{soluble}$ and 92±6% for $COD_{particulate}$. The major part of TSS and VSS was removed in the AH reactor, and little additional removal occurred in the PTF system (Table 2).

The total process achieved an overall removal efficiency of 97±1.2%; 96±1.4% and 92.1±2.3% for TSS at total HRTs of 14, 10 and 7.2 h, respectively. The available data indicates that unique contributions of each technology component to the efficiency of the total treatment system i.e. AH reactor was effective for removal of COD fractions (COD_{total}, $COD_{soluble}$ and $COD_{particulate}$), TSS and VSS . By capturing the COD and suspended particles early in the AH process, most of the volatile and oxygen-demanding organic matters were removed in PTF (Table 2).

The removal of COD_{total} and TSS in the AH reactor, improved the nitrification efficiency in PTF as shown in Table 2. This is particularly important in food industry wastewater treatment systems because as shown in Table 2, the effluent after AH system contained significant amounts of TKj-N (28 mg/l), mostly soluble forms of NH_4-N (26 mg/l). The NH_4 –N was efficiently oxidized in the PTF module resulting a removal efficiency of 86±6.5% .

Parameters	COD fractions (mg/l)			Nitrogen species (mg/l)			Solids (mg/l)	
Run 1	Total	Soluble	Particulate	TKj-N	NH_4-N	NO_x-N	TSS	VSS
Wastewater	999.7±337	388±157	612±309	33±6	24.3±5	-	416±95	344±37
AH- effluent	267±48	121.4±40	145±59	28±6	26±5	-	98±23	77±14
PTF- effluent	34.7±8.5	27.4±4.7	7.3±7	4.8±2	2.7±1.4	18±3.6	12.2±3.2	8±1.4
Overall removal efficiency	96±2	92±3.5	98±2.4	85±6	88.6±6.5	-	97±1.2	98±0.5
Run 2								
Wastewater	883±285	344±65	539±267	33±5.7	26.1±5.4	-	437.2±160	266±79
AH- effluent	248±61	118±11	131±65	28.4±6	28±6	-	100.3±18	77±18
PTF- effluent	40±8.5	31±6	10±7	6±1.8	2.8±1.3	17.1±4.5	13±2.8	8.3±2
Overall removal efficiency	95±2.2	91±3	97.4±2.6	83±5.3	88.9±5.2	-	96±1.4	96.5±2
Run 3								
Wastewater	795±168.4	223±59	572±193	32.3±5	23±4.6	-	387.4±48	300±65
AH- effluent	377±89	134.5±23	242.8±89	26±5	24±4.6	-	143.2±17.7	124±12
PTF- effluent	86±16	49.7±10.7	36±23	21±4	17.8±3.7	1.7±0.9	30±5	25±5
Overall removal efficiency	88.7±3.3	76±9.1	92±6	36.3±9	21.2±9.4	-	92.1±2.3	91.3±2.5

Table 2. Overall removal efficiencies of the total process (AH + PTF) treating tomato industry wastewater

3.5. Scanning electronic microscope (SEM) observation

Typical SEM images of porous polyurethane of PTF reactor are shown in Fig. 12. Microorganisms were attached to the porous polyurethane packing material (Fig. 12). The presence of microorganisms in the PTF not only oxidizes ammonia, but also improves the adsorbent and oxidization capability of e organic matter in the wastewater.

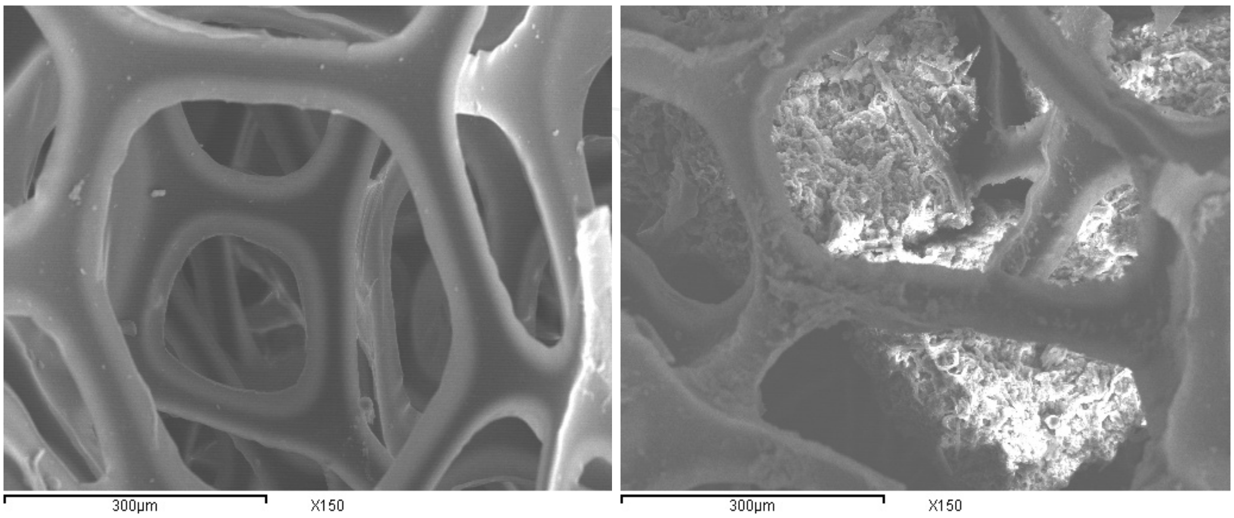


Figure 12. SEM photographs of the microorganisms forming the biofilm in the bioreactor. (a) The clean polyurethane media before attachment of microorganisms; (b) the same surface of the polyurethane after the attachment of microorganisms.

4. Conclusions

- The results obtained revealed that the combined system (AH+ PTF) is very effective for the treatment of tomato industry wastewater at a total HRT not exceeding 10 h. The total process removed 96% of COD $_{total}$, 92% of COD $_{soluble}$, 98% of COD $_{particulate}$, 85% of TKj-N, 89% of NH_4 –N, 97% of TSS, and 98% of VSS. The effluent quality is complying for reuse and /or discharge according to Egyptian standards for discharge.
- The experimental results obtained here demonstrated that AHreactor and PTF was capable of operating efficiently at short HRT and high values of OLR in the treatment of tomato industry wastewater. Therefore, the volume of the reactor could be reduced five times in comparison with that used in conventional treatment systems without affecting the organic matter removal and nitrification efficiency.

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Acknowledgement

The author is very grateful for Prof. M. Salem, Prof. R. Abdel Wahab, Dr. A. Al-Asmer, A. Elmitwalli and Prof. Maei for their support and help.

Abbreviations

Trickling filter: TF
Total suspended solids: TSS
Chemical oxygen demand: COD
Up-flow anaerobic sludge blanket: UASB
Anaerobic filter: AF
Anaerobic hybrid: AH
Biodegradable organic matter: BOM
Hydraulic retention time: HRT
Organic loading rate: OLR
Polyurethane trickling filter: PTF
Anaerobic baffled reactor: ABR
Volatile suspended solids: VSS

Dissolved oxygen: DO
Total Kjeldahl nitrogen: (TKj-N),
Thermal conductivity detector: TCD
gCOD removed: gCOD R
Sludge residence time: SRT
Total nitrogen: TN
Mixed liquor suspended solids: MLSS
Mixed liquor volatile suspended solids: MLVSS
Polyvinyl chloride: PVC
Influent wastewater: Influent WW
anaerobic hybrid effluent: AH-eff.
Percentage removal: %R
Volatile fatty acids: VFAs
Influent expression: Inflow wastewater
Effluent expression: Treated wastewater
Anaerobic hybrid effluent: AH-eff
Polyurethane trickling filter effluent: PTF-eff
Scanning electron microscope:SEM
Flame ionization detector: FID
NOx-N: NO3-N + NO2-N

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