

Şevket TULUN¹

TREATMENT OF LEACHATE USING UP-FLOW ANAEROBIC SLUDGE BLANKET REACTORS/VERTICAL FLOW SUBSURFACE CONSTRUCTED WETLANDS

Abstract: The composition of local solid waste consists mainly of biodegradable waste with high moisture and organic content. After being landfilled, the waste decomposes through a series of combined physico-chemical and biological processes, resulting in the generation of landfill leachate. Unless treated properly, the leachate poses a serious threat to the environment and to public health. In this study, the use of an engineered system consisting of an up-flow anaerobic sludge blanket reactor and a vertical flow subsurface constructed wetland for the treatment of landfill leachate was investigated. The leachate obtained from a landfill facility in Aksaray, Turkey was fed into both systems and laboratory tests showed that, over the 6-week study period, the systems were able to efficiently remove chemical oxygen demand (88.6 %) and total nitrogen (80.7 %). The results of this study suggested that *Typha angustifolia* significantly increased the removal of total nitrogen. The higher ammonia removal occurred in the anaerobic system and also the removal efficiency increased in planted bed, it is presumed to be the result of the ammonia nitrogen uptake by the roots of the plant.

Keywords: anaerobic treatment, constructed wetlands, landfill leachate, up-flow anaerobic sludge blanket, water treatment

Introduction

With rapid economic developments and an increase in affluent lifestyles have led to the production of huge amounts of municipal solid wastes that are usually discarded in sanitary landfills, which is a relatively simple low cost procedure [1-3]. Landfills are operated in a modern engineered way to accelerate waste decomposition and gas production. These landfills generate a very complex wastewater, usually called sanitary landfill leachate [4].

Leachate is primarily generated as a result of precipitation falling on active landfill surfaces, but can also be generated as a result of groundwater inflow, surface water runoff, moisture from deposited waste, and biological decomposition [5].

Landfill leachate can be characterized as a water-based solution of four pollutant groups: dissolved organic matter, inorganic macro components, heavy metals, and xenobiotic organic compounds [6]. These pollutants pose notable environmental concerns [7, 8].

Various methods such as coagulation/flocculation, sedimentation/flotation and aerobic and anaerobic processes have been applied for landfill leachate treatment [9-13].

¹ Department of Environmental Engineering, Engineering Faculty, Aksaray University, 68100, Aksaray, Turkey, phone +90 382 288 3605, fax 90 382 288 2298, email: sevkettulun@gmail.com

Bioreactors with long bio solids retention time such as the up-flow anaerobic sludge blanket (UASB) process are widely used for the anaerobic treatment of landfill leachate [14]. It is known that the high biomass concentration of the UASB process can accommodate organic loading rates several times higher than those of other types of anaerobic processes [15, 16]. These properties only require a relatively small volume reactor for treating large wastewater flows. Other advantages of the UASB system are in more rapid restart than other anaerobic systems without requiring reseedling and in the ability to work well under intermittent operations [17]. In Table 1, a review of landfill leachate treatment using UASB reactors and a summary of the operating conditions and performances are presented.

Table 1

Performance of the UASB reactor in landfill leachate treatment

Reactor type	Organic Loading Rate, OLR [kg COD · (m ³ d ⁻¹)]	Removal efficiency [%]			Ref.
		Chemical Oxygen Demand, COD	Biochemical Oxygen Demand, BOD	Total Nitrogen, N _{tot}	
UASB	0.6	95.4	90.2	-	[18]
UASB	12.5	82.4	-	-	[19]
UASB	12.7	93.5	-	99.1	[20]
UASB	6.73	42.2	-	-	[21]

Wetland systems have many functions, the most important one of which is the ability to retain, transform or degrade pollutants [22]. The use of constructed wetlands is low-cost, with minimal operation and maintenance requirements compared to conventional wastewater treatment facilities. Constructed wetland systems are frequently used for the treatment of high volume dilute wastewaters, such as landfill leachate and acid mine drainage [23].

Typha angustifolia is an abundant aquatic plant existing in various regions of the world [24]. *T. angustifolia*, an invasive species, is capable of displacing and hinder the growth of other plants with its allelopathic root exudates [25]. This species has dense monospecific stands and extensive root systems, which harbor specific microbial communities [26]. Because of these properties, *T. angustifolia* can be used in natural treatment systems. Table 2 summarizes the data from various studies conducted on the treatment of landfill leachate using constructed wetlands.

Table 2

Treatment performance of constructed wetlands in organic matter and nitrogen removal

Sample	Influent organic matter [g · dm ⁻³]	Influent nitrogen [g · dm ⁻³]	Method	Plants were used	Removal efficiency [%]			Ref.
					COD	Ammonium NH ₄ -N	N _{tot}	
Landfill leachate	4.360	0.046	Free water surface	<i>Cattail</i>	20	44	13	[27]
Landfill leachate	4.770	2.865	Horizontal subsurface flow	<i>Typha latifolia</i>	36	38	-	[28]
Landfill leachate	1.108	0.176	Horizontal subsurface-flow	Sludge plants	53	40	-	[29]
Landfill leachate	0.202	0.086	Vertical subsurface-flow	<i>Phragmites australis</i>	84	83	74	[30]

To Author's best knowledge, there are no studies about using lab-scale UASB reactors/vertical subsurface flow constructed wetlands (VSFCW) with *T. angustifolia* for the treatment of landfill leachate. The main objective of the present study, which was conducted in Aksaray University in 2018 was to investigate the effects of UASB reactors on organic matter removal and the performance of VSFCW on landfill leachate. This study also aimed to determine the effect of treatment on the chemical oxygen demand, *COD* and total nitrogen, N_{tot} parameters and assess the effects of the treatment of leachate anaerobic digestion performance in terms of operation time.

Materials and methods

Landfill leachate

The inter municipal sanitary landfill facility of Aksaray, Turkey managed by the municipality serves a population of 300,000 inhabitants within 30 districts, covering an area of 108,085 km², which is mostly rural. This landfill facility which has a capacity of 10,800 m³, has been filled since 2006. The leachates produced in this landfill facility are of medium age sanitary. Landfill leachate used for this study was obtained from the Aksaray Landfill Facility, and kept in a refrigerator (+4 °C). Due to the difficulty of obtaining leachate during winter months, a batch of leachate sufficient for the entire experiment was collected a year before the study was conducted and stored in barrels. Whenever additional feed leachate was required during the experiment, a barrel would be moved to an adjacent refrigerator allowing the leachate to thaw in 4 °C.

Characterization of the landfill leachate during the study period

Table 3

Parameters	Values		
	Number of measurements, <i>n</i>	Mean value, X_{ort}	Standard deviation value, <i>SD</i>
pH [-]	15	7.56	0.08
Electrical conductivity, <i>EC</i> [mS · cm ⁻¹]	15	5.63	0.10
<i>COD</i> [g · dm ⁻³]	15	19	17
<i>BOD</i> ₅ [g · dm ⁻³]	15	6.9	5.7
Total Organic Carbon, <i>TOC</i> [g · dm ⁻³]	15	6.4	5.9
N_{tot} [g N · dm ⁻³]	15	1.6	1.2
Sulfate [g SO ₄ ²⁻ · dm ⁻³]	15	0.64	0.46
Phosphate [g PO ₄ ³⁻ · dm ⁻³]	15	0.106	0.104

The raw leachate had a pungent smell and a black-brownish colour, which indicated that the leachate contained a considerable amount of colloids and fine solids. The total solid, *TS* concentration of the leachate was 14.20 kg · m⁻³ while its volatile solid, *VS* concentration was 6.30 kg · m⁻³. The leachate was extracted in a quantity of 20 dm³ by siphoning when required. Prior to siphoning, barrel contents were stirred manually.

UASB reactor set-up

The UASB reactor was made of stainless iron with an approximate volume 11.3 dm³ (effective volume of 2.5 dm³). The reactor was housed in a laboratory, the temperature of which was controlled at 25 ± 1 °C. The reactor was 0.06 m an internal diameter and 1.0 m in height. The influent inlet was placed at the bottom through a T-shaped connector.

The vertical orientation of the tubing often caused a clogging problem in the influent tubing due to the falling of granules from the reactor, which in turn required the tubing to be cleaned regularly. The reactor was operated to achieve a quasi-steady state and stable operation before the shock loads were applied. In starting up a run, the reactor was fed with diluted landfill leachate ($5000 \text{ mg COD} \cdot \text{dm}^{-3}$) in an intermittent feeding pattern. The volatile fatty acid (VFA) concentrations were observed by the controlling the pH of the medium and, if they were not detected within 48 hours, the feed flow rate was increased by another 20-minute increment. The feed *COD* concentration was increased, and the flow rate was also increased until the desired hydraulic retention time (HRT) and *COD* level in the feed ($20000 \pm 1500 \text{ mg COD} \cdot \text{dm}^{-3}$) was achieved. The start-up period took approximately 4 weeks when the reactor was idle. A 20 dm^3 influent plastic tank was used to feed the UASB reactor with the leachate sample. A feed pump was used to feed the leachate sample to the reactor and the pump rate was set at $4 \text{ dm}^3 \cdot \text{d}^{-1}$. The recirculation rate used consisted in 0.5 hours of recirculation every 4 hours over a period of 24 hours. The recirculation pump was stopped 2.5 hours before and during the feeding time. After the feeding time, the pump was turned on again. Wastewater effluent from the anaerobic reactor was given to the VSFCW reactor. The sampling was performed by determined time intervals 1-42 days.

VSFCW reactor set-up

The VSFCW used in this study was approximately $0.6 \times 0.45 \times 0.3 \text{ m}$ (length $\times$ width $\times$ height) and was run parallel to the UASB reactor and planted with reeds. *T. angustifolia* was selected and planted into the VSFCW at a density of 40 stems m^{-2} . The effective surface areas were approximately 0.26 m^2 and the bed was filled with different size aggregates (0.09 m sand, 0.12 m medium gravel and 0.09 m large gravel). The water table was fixed at 0.3 m. One sampling point was used as an outlet piece in the VSFCW to collect water samples for analytical measurements as shown in Figure 1. The sampling was performed by determined time intervals 1-42 days.

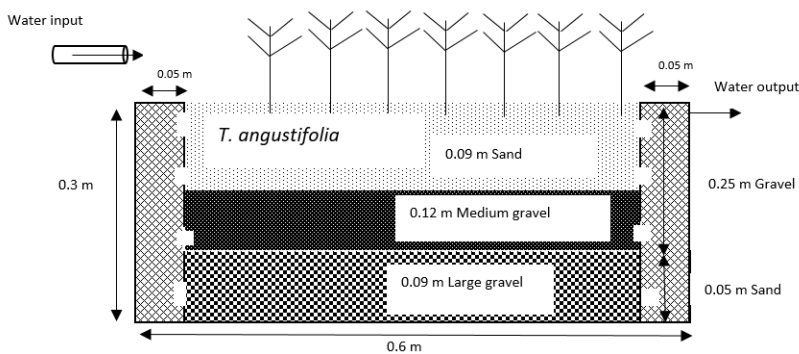


Fig. 1. Laboratory set-up of VSFCW

Landfill leachate from anaerobic treatment effluent was fed to the VSFCW. The leachate entered the beds through a plastic reservoir that was located directly over the inlet zone which was constructed of large gravel that reached the bottom of the beds. One small hole was punctured in the bottom of the reservoir to regulate flow $4 \text{ dm}^3 \cdot \text{d}^{-1}$ of

wastewater with a hydraulic loading rate (HLR) of $20.78 \text{ mm} \cdot \text{d}^{-1}$ was introduced into the VSFCW.

Analyses

Physical parameters such as pH, conductivity, and temperature were measured using a multi-function Orion Research instrument. Solution pH was measured with an accuracy of ± 0.02 . *TOC* and N_{tot} were measured using a *TOC-N_{tot}* (Shimadzu TOC-VCPN) analysis system. Sulfate and phosphate were analyzed by an ion chromatograph (DIONEX ICS-1000 Detector with Peak Net 6.4Software). *COD* was determined by closed reflux titrimetric method in accordance with the procedure described in Section 5220C of Standard Methods [31]. *BOD* was determined by the respirometric method in accordance with the procedure described in Section 5210D of Standard Methods [31]. This method provided the direct measurement of the oxygen consumed by microorganisms from an air enriched environment, in a closed vessel, under conditions of constant temperature (20 ± 1 °C) and stirring. The assays were performed in a WTW Oxitop IS 12 Inductive Stirring System (WTW TS 606-G/2-i). Suspended solids, *SS*, were determined in accordance with the procedure described in Section 2540 D of Standard Methods [31]. In this method, a well-mixed sample is filtered through a weighted standard glass-fiber filter (Whatman GF/F filter, $0.45 \mu\text{m}$) and the residue retained on the filter is dried to a constant weight between 103 and 105 °C. The increase in weight of the filter represents the *SS*.

Results and discussion

Leachate characterization

A characterization of the selected parameters for the leachate was made for the samples collected during a period of 42 days. The composite leachate samples were taken at 0.5-1.0 m depth measured from the ground. The relevant physicochemical characteristics of the Aksaray landfill leachate facility samples collected during the research period are summarized in Table 3. The composition of the leachate was relatively constant over the research period. The leachate was characterized as having a neutral pH, dark colour, low concentration of biodegradable content as represented by *BOD*, sulfate concentration higher than $600 \text{ mg} \cdot \text{dm}^{-3}$ with a strong sulfur odor and high concentration of refractory organic matter represented by *COD*. These values indicate that the landfill, which was largely in the second phase of anaerobic digestion, was of a mature and stabilized characteristics. The *BOD/COD* ratio indicates the degree of treatability by means of biological methods. In addition, this ratio is also a rough indication of the age of the landfill. The leachate from landfills had an average *BOD/COD* ratio of 0.35 and pH above 7. These values reveal that approximately 35 % of the organic matter should be biodegradable. These types of leachate are characterized as refractory to conventional biological treatment processes and require consecutive biological treatment processes for treatment. In summary, the characteristics of the leachate (Table 1) were comparable with the leachate of a mature and stabilized landfill. The *COD* average of $18.9 \text{ g} \cdot \text{dm}^{-3}$, and the *BOD/COD* ratio of 0.35 are characteristics of a leachate emanating from a medium aged (8-10 years) landfill. It should be noted that the actual site age of the Aksaray Landfill facility is 13 years. Therefore, the characteristics of the leachate do not seem to be in compliance with the chronological classification for the age of landfills. The reason for this is that the landfill is currently still under operation.

COD removal from the system

The organic matter removal was inspected by observing the *COD* during the experimental study period. The *COD* concentration and its removal percentages from the leachate for each reactor are given in Figure 2. The feed tank (20 dm^3) was feeded every 3 days. So the initial concentrations of *COD* was changed daily, so the concentrations of *COD* was calculated.

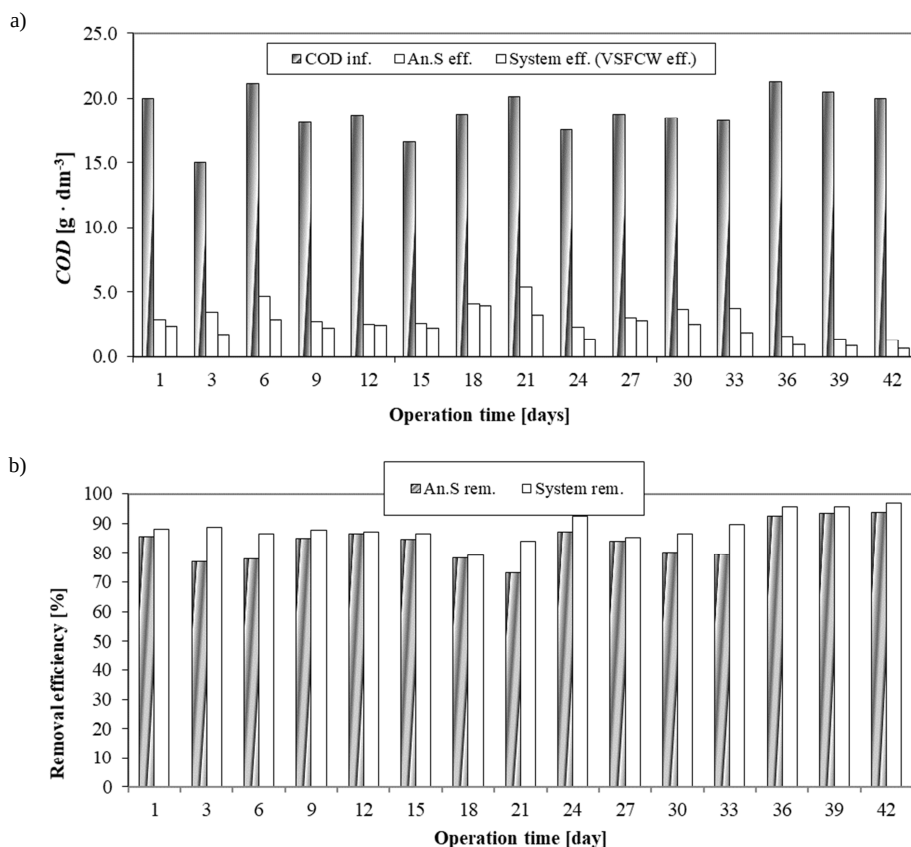


Fig. 2. a) *COD*, b) removal efficiency in the systems

The feed concentration of $18.9 \text{ g COD} \cdot \text{dm}^{-3}$ was tested. At the end of the operating period, *COD* removal efficiencies were obtained as 84.3 % in the UASB reactor and 88.6 % in the system. The removal efficiencies of the UASB reactor were obtained in the range of efficiencies for general biological treatments. A smaller *COD* removal efficiency was obtained in the VSFCW. This may be the result of a change in the microbial community which, in turn, caused a change in the VSFCW. At the end of day 42, the *COD* value decreased to $0.655 \text{ g} \cdot \text{dm}^{-3}$ at the system output. The residual organic content or the *COD* on day 42 can be interpreted as the non-biodegradable portion of the content.

N_{tot} removal from the system

VSFCWs are generally a valuable tool for removing nitrogen from wastewater. In many conditions, ammonium nitrogen removal is possible either through nitrification or plant uptake. This section illustrates the N_{tot} performance of all reactors as well as the overall system performance. Figure 3 shows the N_{tot} removal.

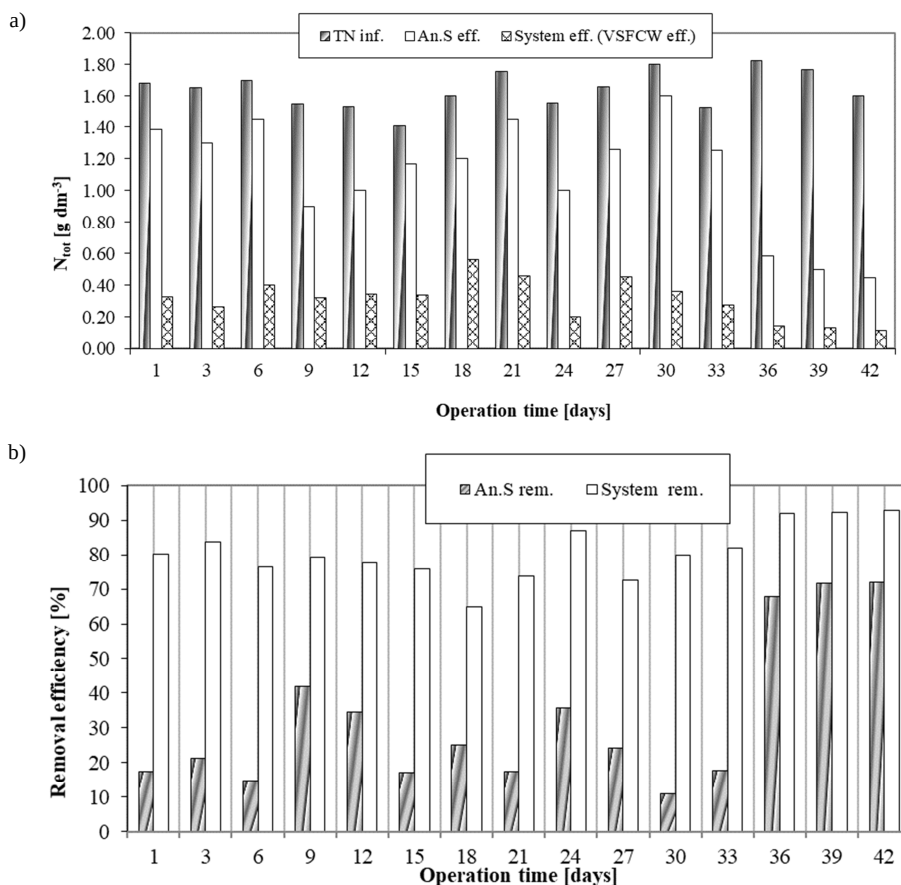


Fig. 3. a) N_{tot} and b) removal in the overall system performance

The feed tank (20 dm^3) was feeded every 3 days. So the initial concentrations of N_{tot} was changed daily, so the concentrations of N_{tot} was calculated. As it can be seen from Figure 4, during the UASB anaerobic treatment period, the average N_{tot} influent was $1640 \text{ mg} \cdot \text{dm}^{-3}$ and removal efficiency performance was 32.6 %. As nitrogen is oxidized in the VSFCW, N_{tot} removal rates were higher when the VSFCW was used. As the process of nitrification-denitrification is recognized as the primary process responsible for the removal of nitrogen in VSFCWs, it can be concluded that the nitrogen removal efficiency is high due to the amount of oxygen present in these systems. In addition, the removal of N_{tot} was

high in the initial stages of the system, which is when nitrifying bacteria were likely experiencing high growth rates and, therefore assimilating more nitrogen.

Conclusion

Over the last years, constructed wetlands have been shown to be environmentally sustainable systems that can successfully treat wastewater generated from different sources, particularly by removing organic load and nitrogen. Constructed wetlands are advantageous due to their characteristics such as the recovery of the investment and operational costs, the protection and improvement of the natural ecosystems and the quality of life of population. Within the scope of the present study, a 6-week treatability study was conducted to evaluate the performance of a VSFCW system (*T. angustifolia* plants) and an anaerobic system (UASB) to determine the benefits of using these systems in treating landfill leachate. When the UASB and VSFCW systems were compared, it was found that the UASB reactor had the highest treatment performance in terms of *COD*. The notable benefit of the UASB system was the removal of dissolved inorganic constituents and *COD* prior to subsequent VSFCW systems, which increases the effective life of each of the treatment systems. Both treatment systems efficiently removed *COD* (88.6 %) and N_{tot} (80.7 %). The results highlight the key role of the presence of *T. angustifolia* in N_{tot} removal and, consequently, it can be concluded that the use of this plant in constructed wetlands can be a determinant factor in meeting the limit emission values for the discharge of wastewater into surface water bodies. The higher ammonia removal in the planted bed is thought to be the result of the ammonia nitrogen uptake by the roots.

References

- [1] Miao L, Yang G, Tao T, Peng Y. J Environ Manage. 2019;235:178-85. DOI: 10.1016/j.jenvman.2019.01.057.
- [2] Eskandari M, Homae M, Mahmoodi S, Pazira E, Van Genuchten MTh. Environ Sci Pollut Res. 2015;22:7754-65. DOI: 10.1007/s11356-015-4182-7.
- [3] Talalaj AI. Int J Environ Sci Technol. 2015;12:2791-800. DOI: 10.1007/s13762-014-0661-5.
- [4] Sujetovienė G, Smilgaitis P, Dagiliūtė R, Žaltauskaitė J. Waste Manage. 2019;85:60-5. DOI: 10.1016/j.wasman.2018.12.017.
- [5] Islam M, Wai A, Hausner G, Yuan Q. J Environ Manage. 2019;233:400-9. DOI: 10.1016/j.jenvman.2018.12.045.
- [6] Baderna D, Caloni F, Benfenati E. Environ Int. 2019;122:21-30. DOI: 10.1016/j.envint.2018.11.024.
- [7] Poblete R, Oller I, Maldonado MI, Cortes E. J Environ Manage. 2019;232:45-51. DOI: 10.1016/j.jenvman.2018.11.030.
- [8] Berenjkari P, Islam M, Yuan Q. Int J Environ Sci Technol. 2019;16:2465-74. DOI: 10.1007/s13762-018-1889-2.
- [9] Kurniawan TA, Lo W-H, Chan GYS. J Hazard Mater B. 2006;129:80-100. DOI: 10.1016/j.jhazmat.2005.08.010.
- [10] Nair AT, Senthilnathan J, Nagendra SMS. J Water Proc Eng. 2019;28:322-30. DOI: 10.1016/j.jwpe.2019.02.017.
- [11] Dia O, Drogui P, Buelna G, Dubé R. Waste Manage. 2018;75:391-9. DOI: 10.1016/j.wasman.2018.02.016
- [12] Tripathy BK, Kumar M. J Environ Chem Eng. 2017;5:6165-78. DOI: 10.1016/j.jece.2017.11.039.
- [13] Liu Z, Duan X, Zhan P, Liu R, Nie F. Int J Environ Sci Technol. 2017;14:2507-18. DOI: 10.1007/s13762-017-1338-7.
- [14] Liu M, Yang Q, Peng Y, Liu T, Xiao H, Wang ST. J Ind Eng Chem. 2015;32:63-71. DOI: 10.1016/j.jiec.2015.07.017
- [15] Katsoni A, Mantzavinos D, Diamadopoulos E. Water Res. 2014;57:76-86. DOI: 10.1016/j.watres.2014.03.010.

-
- [16] Govahi S, Karimi-Jashni A, Derakhshan M. *Int J Environ Sci Technol.* 2012;9:145-51. DOI: 10.1007/s13762-011-0021-7.
- [17] Chen C, Liang J, Yoza BA, Li QX, Zhan Y, Wang Q. *Bioresour Technol.* 2017;243:620-7. DOI: 10.1016/j.biortech.2017.06.171.
- [18] Bohdziewicz J, Kwarcia A. *Desalination.* 2008;222:128-34. DOI: 10.1016/j.desal.2007.01.137.
- [19] Ye J, Mu Y, Cheng X, Sun D. *Bioresour Technol.* 2011;102:5498-503. DOI: 10.1016/j.biortech.2011.01.001.
- [20] Sun H, Peng Y, Shi X. *Bioresour Technol.* 2015;177:337-45. DOI: 10.1016/j.biortech.2014.10.152.
- [21] Lin C-Y, Chang F-Y, Chang C-H. *Bioresour Technol.* 2000;73:175-88. DOI: 10.1016/S0960-8524(99)00166-2.
- [22] Williams JB. *Crit Rev Plant Sci.* 2002;21:607-35. DOI: 10.1080/0735-260291044386.
- [23] Dierks S. *Water Sci Technol.* 2001;44:477-83. DOI: 10.2166/wst.2001.0869.
- [24] Boumaz S, Yenounne A, Hachi W, Kaouah F, Bouhamidi Y, Trar M. *Int J Environ Res.* 2018;12:561-73. DOI: 10.1007/s41742-018-0111-1.
- [25] Callaway RM, Ridenour WM. *Front Ecol Environ.* 2004;2:436-43. DOI: 10.1890/1540-9295(2004)002[0436:NWISAT]2.0.CO;2
- [26] Angeloni NL, Jankowski KJ, Tuchman NC, Kelly JJ. *FEMS Microbiol Lett.* 2006;263:86-92. DOI: 10.1111/j.1574-6968.2006.00409.x.
- [27] Ogata Y, Ishigaki T, Ebie Y, Sutthasil N, Chiemchaisri C, Yamada M. *Waste Manage.* 2015;44:164-71. DOI: 10.1016/j.wasman.2015.07.019.
- [28] Yalcuk A, Ugurlu A. *Bioresour Technol.* 2009;100:2521-6. DOI: 10.1016/j.biortech.2008.11.029.
- [29] Nivala J, Hoos MB, Cross C, Wallace S, Parkin G. *Sci Total Environ.* 2007;380:19-27. DOI: 10.1016/j.scitotenv.2006.12.030.
- [30] Feo De G. *J Environ Sci Health A.* 2007;42(7):1013-20. DOI: 10.1080/10934520701373117.
- [31] Bilgin M, Şimşek İ, Tulun Ş. *Ecol Eng.* 2014;70:362–65. DOI: 10.1016/j.ecoleng.2014.06.