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An innovative technology for treating wastewater generated at the University of Murcia

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ABSTRACT

A wastewater treatment plant of an innovative technology, designed by Golftrat S.L., was constructed to evaluate its success in treating the wastewater generated from various installations in the Campus of Espinardo (University of Murcia). The cited technology, named "symbiotic plant®", combines a natural and subterranean treatment with the generation of green areas over the surface of the plant. It is a promising technology, when comparing with conventional system, due to the low energy cost and the simple operational and maintenance procedures. In spite of the variation in the characteristics of the wastewater generated at the University, a great homogeneity in the quality of the effluent is obtained. The removal efficiency is up to 95% for COD, 97% for BOD, up to 87% for suspended solids, up to 80% for nitrogen and at least 40% for phosphorus. Besides, an increasing in dissolved oxygen is obtained along the treatment with the consequent increase in nitrates concentration. With the final treatment in the wetland an important level of denitrification is achieved. The overall treatment plant provides an effluent with enough quality to be used for irrigation of the green areas in the Campus of Espinardo.

Keywords: Innovative technology; Urban wastewater; Small village; Nitrification-denitrification

1. Introduction

Wastewater treatment is becoming ever more critical due to diminishing water resources, increasing wastewater disposal costs, and stricter discharge regulations that have lowered permissible contaminant levels in waste streams. The treatment of wastewater for reuse and disposal is particularly important. In this sense, the Directive 91/271/EEC [1] concerning urban wastewater treatment requires all towns with less than 2000 equivalent inhabitants to have a collection system in place to treat adequately their effluent.

The conventional treatment systems have some disadvantages such as high cost, and operational difficulties due to fluctuations in wastewater flow rate and pollution loads [2]. Given the need to seek alternative solutions to conventional system, priority has been given to those technologies which have a minimum or null energy cost, with simple operational and maintenance procedures, and which guarantee efficiency and a high level of inertia when faced with large fluctuations in the flow and the effluent load to be treated, and which simplify sludge handling processes. The treatment technologies which bring together all of these characteristics are generally known as non-conventional technologies [3].

The University of Murcia has conscience of the necessity to treat their wastewater for reusing. Due to the increasing in the number of centres, the old wastewater treatment plant, consisting in a deep wastewater stabilisation pond, has remained insufficient to treat the

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overall wastewater generated at the Campus of Espinardo. So, it was necessary to install a new wastewater treatment plant, preferably with non-conventional technologies.

An innovative technology, named "symbiotic plant®" [4], was selected for this purpose. It is a clean and ecological technology, and has as its main characteristic and advantages the existence of two well-distinguished areas, the depuration area and the cultivation area. The water is applied underground to a gravel bed over which a green area is situated. So, the evaporation losses are minimal, the green areas can be used even during irrigation and direct contact of users of such areas with residual waters is prevented.

After carrying out diverse assays at pilot scale and verifying the suitability of the cited technology for treating the wastewater from the university installations and a nearby housing development [5], ESAMUR (Wastewater Treatment Organisation of Murcia) had provided the economic support to carry out the construction and the scientific study of "An experimental symbiotic wastewater treatment plant" in the Campus of Espinardo (University of Murcia). In this paper, the results of a physicochemical control of this pioneering plant, during the first year of operation, are presented in order to demonstrate the success of this system to treat the wastewater generated at the University of Murcia and the possibility of applying this technology to the wastewater generated in small villages.

2. Methodology

2.1. Experimental wastewater treatment plant of the University of Murcia

The wastewater treatment plant, designed by Golftrat, S.L. for treating 500 m^3/d, is integrated by a physical treatment and the symbiotic treatment. A flowsheet of the plant is shown in Fig. 1.

The symbiotic treatment (Fig. 2) consists of a depuration area, 120 cm thick of gravel bed, which is isolated from the ground by a waterproof layer. A network of subterranean drippers, placed directly on the gravel, is used to apply the wastewater. The cultivation area, composed by approximately 30 cm of sandy substrate, is situated over the depuration area. The whole depuration process consists of four sequential stages of treatment with a filtering surface of 205 m^2/stage.

The wastewater is pretreated before entering the symbiotic plant. The pretreatment consists of a grid, two subsequent rotatory sieves with 0.5 and 0.25 mm sieve openings, respectively, and a series of twelve 125 µm mesh ring filters. Pretreated wastewater enters the first stage of the symbiotic plant through the drippers falling by gravity through the gravel bed until it reaches the bottom waterproof layer. The effluent is collected in a deposit and filtered through a series of three 125 µm size mesh filters before being pumped to the next stage. The effluent from the fourth stage is partly discharged to an artificial wetland and partly falls by gravity into a storage pond.

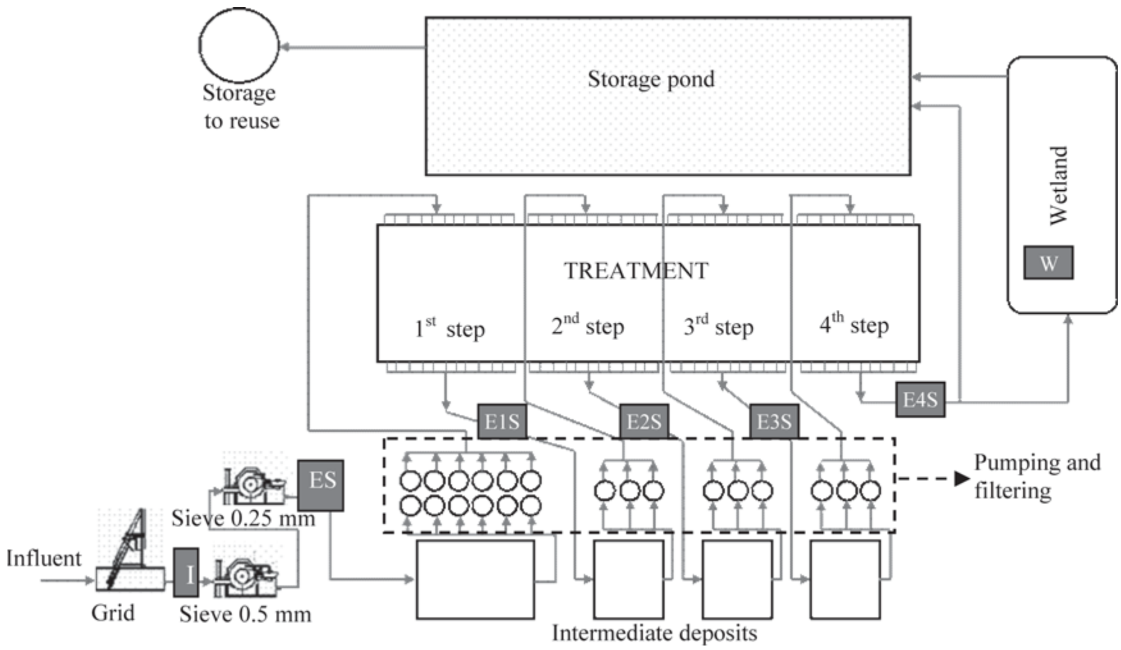

Fig. 1. Flowsheet of the treatment plant and sampling points.

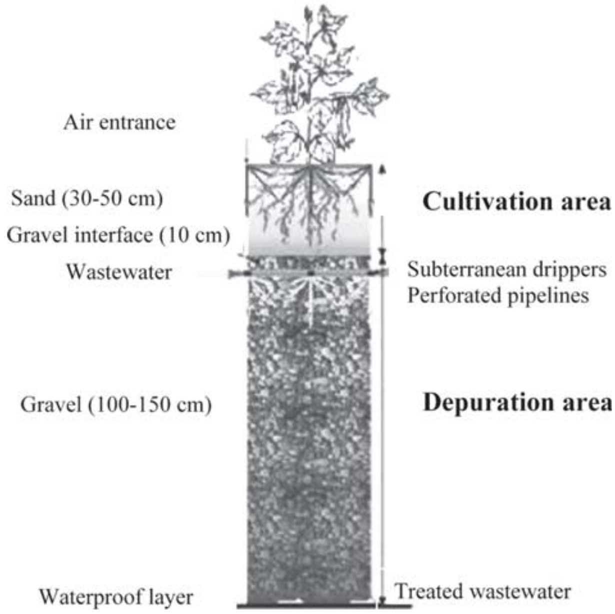

Fig. 2. Diagram of the symbiotic treatment.

A clarifier sludge collects the small amounts of sludge generated by sloughed off biofilm from the surface of the gravel bed and the wash water from cleaning filters and drippers.

2.2. Sampling and methods

Samples were collected twice in a month, over a year period, from influent (I), effluent of the sieves (ES), outlet of the four treatment stages (E1S, E2S, E3S and E4S) and wetland (W) (Fig. 1). Samples were analysed to follow-up several pollution parameters according to the treatment: total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), total kjeldahl nitrogen (TKN), ammonia nitrogen ($N\text{-}NH_4^+$), nitrates, total phosphorus (TP) and phosphates. pH, conductivity and dissolved oxygen (DO) were also measured. All water samples were analysed in accordance with the Standard Methods for Examination of Water and Wastewater [6].

3. Results and discussion

3.1. Influent characterisation

The average composition, standard deviation and the variation range of the parameters measured in raw effluent are shown in Table 1.

Of particular concern is the great variation in the influent flow. It can be noticed that symbiotic beds work at a constant flow of 36 m^3/h and so, hydraulic retention time remains constant. Nevertheless, the changes in flow rate have effects on the overall daily performance of symbiotic beds. With the actual flow, the feed of the symbiotic beds is intermittent.

As can be seen in Table 1, there is also a great fluctuation in wastewater pollution loads. The raw wastewater is comparable to a high strength domestic wastewater [7]. The fluctuation in the wastewater characteristic is mainly due to the location inside the Campus of Espinardo of several activities which generate, in a discontinuous way, wastewater whose composition alters the habitual composition. Some of these activities are: the veterinary hospital, the laundry, the laboratories of the faculty of fine arts, etc. The COD/BOD_5 ratio in the influent oscillates between 1.4 and 2.9 which is indicative of an effluent easily biodegradable. This fact justified the utilisation of a biological system to treat this kind of water.

Table 1
Influent characterisation

Parameter	Minimum value	Maximum value	Average value	Standard deviation
Flow rate (m^3/d)	102	525	264	84
pH	7.13	8.28	7.64	0.36
EC (mS/cm)	1.64	3.55	2.15	0.51
Dissolved oxygen (mg O_2/L)	0.20	5.73	2.49	1.90
Temperature (°C)	18.7	28.2	23.7	3.2
TSS (mg/L)	265	976	518	216
BOD_5 (mg O_2/L)	300	1100	536	235
COD (mg O_2/L)	571	2320	1011	449
TNK (mg N/L)	22.8	59.8	42.2	10.8
$N\text{-}NH_4^+$ (mg N/L)	21.3	51.4	35.2	10.2
Nitrates (mg N/L)	0	0	0	0
TP (mg P/L)	5.8	21.7	11.3	4.1
Phosphates (mg P/L)	2.2	16.7	4.9	3.4

3.2. Evolution of the physico-chemical parameters through the treatment plant

As has been commented above, to study the effectiveness of the treatment plant to depurate the wastewater generated at the Campus of Espinardo (University of Murcia), several physico-chemical parameters has been determined. According to the obtained results, pH values fall well within the optimum range for the growth of the microorganisms for digesting organic matter (6.6–8.5). An increase in the pH value along the symbiotic plant was observed, which indicates that pH is affected by the stripping of CO_2 as a consequence of the aerobic degradation of organic matter. The conductivity remains almost constant along the depuration process and its value oscillate between 1.7 and 2.8 mS/cm.

The evolution of the rest of parameters along the depuration process is illustrated in box plots (Figs. 3–7). The upper and lower box indicate 25th and 75th percentile, the whiskers are the 5th and 95th percentile, the symbols represent the outliers, the solid line is the median and the dashed line is the mean.

3.2.1. Dissolved oxygen

The dissolved oxygen is one of the most important parameters in this system. The gravel bed remains unsaturated at all times, so the water which irrigate the gravel bed is always in contact with air, and so that depuration is carried out in aerobic conditions. As it can be noticed (Fig. 3), the concentration of dissolved oxygen increases along the steps of the symbiotic plant. The increase in dissolved oxygen concentration enhanced the organic matter oxidation, the hydrolysis of organic nitrogen compounds and the activity of the bacteria in general but also the metabolism and activity of the bacteria responsible for the nitrification process.

One of the advantages of this system is that oxygen transfer is attained by natural means instead of mechanical aeration methods which require high capital, energy and maintenance. The main route for oxygen transport from air is atmospheric oxygen diffusion as consequence of the concentration gradient and also as consequence of the demand exercised by the organic matter.

In the last samplings the increasing in the concentration of dissolved oxygen along the stages was lower. The decrease in dissolved oxygen goes with the apparition of sludge in the deposits which collect the effluent of each stage. Both observations could be related. An increase in biofilm thickness leads to limited oxygen supplies in deeper layers of the biofilm, creating an anaerobic environment near the filter media surface. Due to a reduced supply of organic substrates, organisms in the deeper layers enter into the endogenous phase of growth and are subsequently sloughed off the surface. In spite of this fact, no modifications have been observed in the quality of the final effluent. Note that the sludge rapidly settles in the deposits of treated wastewater and it is collected in the clarifier sludge without interfering in the water quality.

Higher concentrations of dissolved oxygen are achieved within the wetland. The oxygen supply is via the air-water surface exchange and the photosynthesis of the algal biofilms attached to the surface of the emergent aquatic macrophytes present in the wetland.

3.2.2. Total suspended solids

As it can be seen in Fig. 4, the TSS decreases gradually through the process. The sieves, the filters of the first stage and the first symbiotic stage give the major contribution to the removal of suspended solids (percentage removal ranging from 62 to 84%). During this study, the

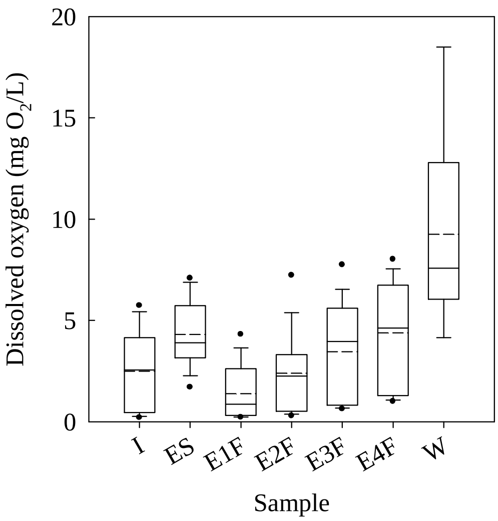

Fig. 3. Box plot of the evolution in dissolved oxygen through the depuration process.

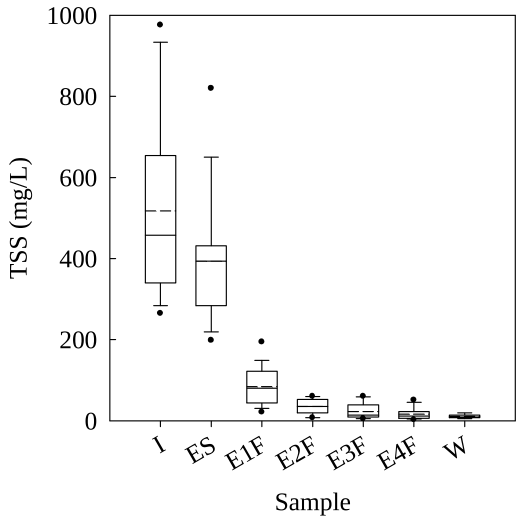

Fig. 4. Box plot of the evolution in total suspended solids through the depuration process.

TSS removal efficiencies of the whole system ranged from 88 to 99% and the effluent concentrations were under the 35 mg/L limit of the European Union (Council Directive 91/271/EEC). It is also observed that, in most of the cases, three treatment phases would be enough to reach the requirements settled down by normative for this parameter.

3.2.3. Organic matter (COD and BOD_5)

From the results illustrated in Fig. 5 it can be noticed that the trends in COD and BOD_5 changes, in terms of concentrations, showed similar behaviour. As it can be seen the concentration for both COD and BOD_5 were gradually decreased throughout the depuration process. The reduction in organic matter could be due to the retention of suspended solids of organic nature in the filter and in the gravel bed, and also to the biodegradation of the organic matter by the living organisms on the gravel bed. A biofilm is generated over the gravel surface which is the main cause of the removal in soluble organic matter in each one of the symbiotic stages. The whole treatment system reduced COD and BOD_5 by an average of 97 and 99%, respectively. The COD and BOD_5 requirement under Directive 91/271/EEC are 125 mg/l O_2 and 25 mg/l O_2, respectively. The treatment plant complies with the Directive and is, in fact, getting stricter standards. Similar to TSS, three stage of treatment would be enough to reach the normative requirement for these parameters.

3.2.4. Nitrogen (TNK, $N\text{-}NH_4^+$ and nitrates)

The concentration of TNK and $N\text{-}NH_4^+$ decreased significantly through the depuration process. The organic nitrogen is decomposed by microorganisms to ammonia nitrogen and ammonium is oxidised to other form of nitrogen (nitrites and nitrates). Results show that nitrate is increasing when ammonium is oxidised (Fig. 6), but no significant levels of nitrite are observed. No losses of nitrogen were observed in the symbiotic plant due to denitrification or volatilization. The overall ammonium removed is transformed in nitrates due to the oxidizing conditions, which in turn favoured aerobic processes such a nitrification. The results show a high nitrification (77–99% removal of ammonia-nitrogen) and a high removal of TKN ranging between 80 and 99%.

On the other hand, a decrease in the nitrates concentrations in the wetland is observed. In the wetland, nitrates are absorbed by aquatic plants.

3.2.5. Phosphorous (TP and phosphates)

As it can be noticed in Fig. 7, the main reduction in phosphorus was obtained in the first stage of the symbiotic treatment. It could be due to the phosphorus retention in filters and gravel bed and also by the assimilation by the microorganisms of dissolved phosphate in the wastewater. No significant differences were obtained in the amount of phosphates through the symbiotic treatment stages. For the overall treatment TP and phosphates mean removal efficiencies were 62% and 10%, respectively.

3.3. Effluent characterisation

Summarizing the above results, this section shows the characterization of the effluent of the symbiotic plant, after the fourth treatment phase. Note that after this phase, the water is partly led to a regulation pond from where it is captured for irrigation and partly is applied to a wetland that contributes to improve the final qual-

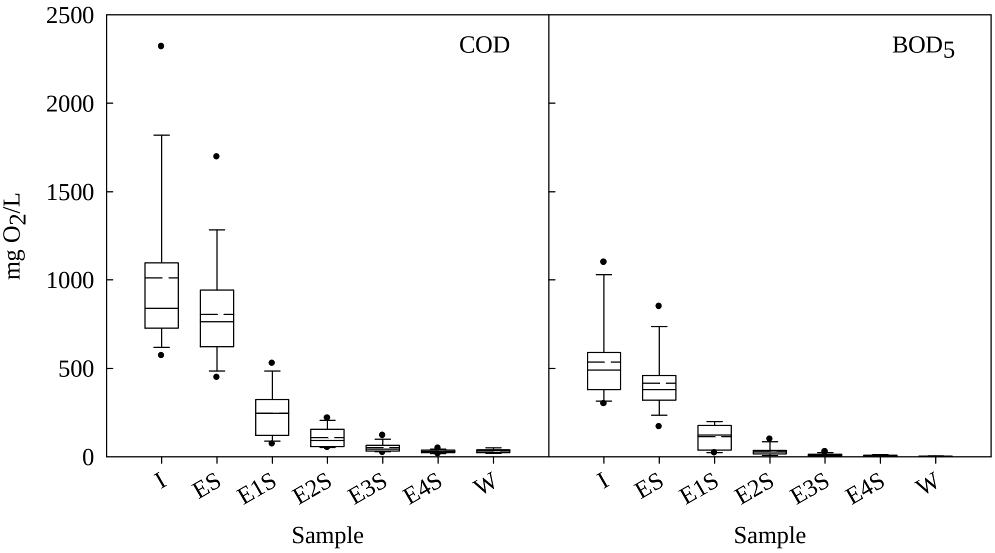

Fig. 5. Box plots of the evolution in organic mater (COD and BOD_5) through the depuration process.

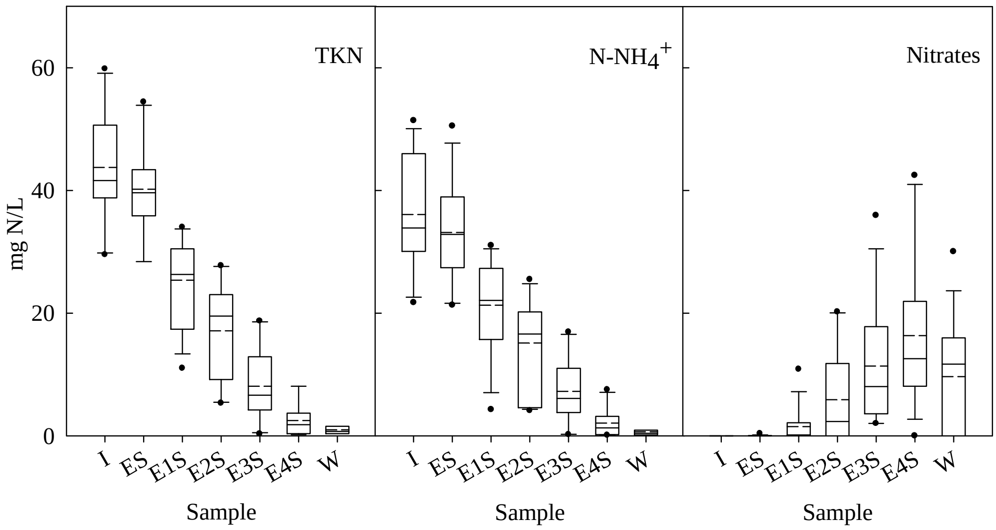

Fig. 6. Box plots of the evolution in TNK, N-NH_4^+ and nitrates through the depuration process.

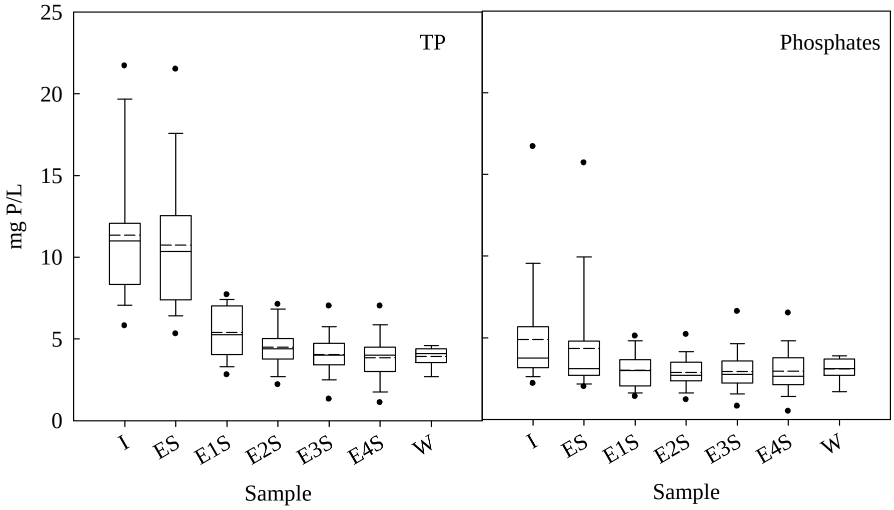

Fig. 7. Box plots of the evolution in TP and phosphates along the depuration process.

ity of the water. Table 2 shows the minimum, maximum and average value (parenthesis) of each one of the parameters studied for the effluent of the fourth treatment phase, as well as the percentage removal.

The treatment applied to this effluent decreased the load of the pollution parameters extensively. In spite of the great variation in the effluent composition and the intermittently fed of the symbiotic stages, the treatment plant performs appropriately and provides water with enough quality to be used for irrigation of the green areas in the Campus of Espinardo, with respect to physicochemical parameters.

It is verified that the quality of the effluent of the treatment plant complies with the Directive 91/271/EEC.

3.4. Operational and maintenance aspects

Symbiotic wastewater treatment systems require minimal operation and maintenance. Nevertheless to prevent or identify problems early the system should be checked on regular basis. Only unpredictable problems which are common also with conventional systems occur, like failures of installation devices (i.e. pumps or valves).

It is necessary to highlight the special configuration of the symbiotic treatment stages. The feeding of the wastewater to a gravel bed through drippers, drop to drop and at a volumetric charge of 0.18 $m^3/h{\cdot}m^2$, assures that the gravel bed is not saturated of water. In more

Table 2
Effluent characterisation

	Range (Average value)	Removal, % (Average value)
pH	6.8–8 (7.3)	
EC (mS/cm)	1.7–2.9 (2.3)	
Dissolved oxygen ($mg\ O_2/L$)	1–8.02 (4.3)	
Temperature (ºC)	16.2–29.3 (23.9)	
TSS (mg/L)	2–31 (14.5)	88.3–99.4 (96.4)
BOD_5 ($mg\ O_2/L$)	1–12 (5.4)	96.8–99.8 (98.9)
COD ($mg\ O_2/L$)	16–48 (30)	92.8–98.7 (96.6)
TNK (mg N/L)	0.2–8.1 (2.3)	79.9–99.7 (87.8)
$N\text{-}NH_4^+$ (mg N/L)	0.1–7.5 (2.0)	76.7–99.8 (87.5)
Nitrates (mg N/L)	6.5–44.8 (25.0)	
TP (mg P/L)	1.1–7.0 (3.9)	12.0–84.3 (62.0)
Phosphates (mg P/L)	0.5–6.5 (2.9)	

that a year of operation, no problem of hydraulic short-circuits or clogging by accumulation of inert material, excess of biomass or decomposition products have been found. The system presents the capacity to remove the excess of biomass. This removed biomass circulates with the water and, given its good sedimentability properties, it settles in the collection deposits of each phase, from where it is sent to a decanter. This decanter receives, also, the wash water from cleaning filters and drippers. Nine daily purges of two minutes each one, in the mentioned decanter, are made. The total volume purged is 1.35 m^3/d, with an average composition of TSS of 4 g/L. The sludge purged is used for composting.

Energy requirements are lower than that for conventional treatment. The estimated overall energy consumption, taking into account pretreatment, filtering, pumping, etc is 0.54 kWh/m^3. Note that there is not a null energy cost as it has been stated for other non-conventional systems, but maybe for this statement the pretreatment and pumping energy cost have not been considered. Also, it has been considered that this system treat a wastewater with a high organic load.

The simplicity in the operation and maintenance, along with the high contaminant removal efficiency, makes this technology attractive for the wastewater treatment in small communities.

4. Conclusions

According to the results obtained in this study, over a year period, it could be concluded that the technology installed at the University of Murcia to treat the wastewater generated in the Campus of Espinardo is efficient, is able to treat fluctuations in the effluent load, do not provide high amount of sludge and it presents a minor cost, with simple operational and maintenance procedures than conventional technologies. In terms of the overall performances the following mean removal rates were obtained: COD 97%, BOD_5 99%, total suspended solids 96%, $N\text{-}NH_4^+$ 87%, total nitrogen 88%, total phosphorus 62%. The system provides an effluent with enough quality to be reused in the irrigation of the green areas. Besides, the experience obtained with this innovative symbiotic plant installed at the University of Murcia could be used to apply this technology to treat wastewater in small villages.

Acknowledgments

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