Start-up of full-scale UASB-vertical flow constructed wetland for domestic wastewater treatment

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Abstract
This work examined the start-up of a full-scale upflow anaerobic sludge blanket (UASB) - vertical flow constructed wetland (CW) for domestic wastewater treatment. The UASB reactors were inoculated with sludge originating from an industrial anaerobic reactor and the start-up period due to the slow growth rate of anaerobic sludge and the low temperatures (<18°C) during this period, expanded the start-up phase to 3 months. After the start-up period, two different operational configurations were studied on the vertical flow constructed wetlands with the application, or not, of internal recirculation between the saturated and unsaturated CW beds. During the 1st period of relatively stable operation, the UASB-CW system (with CWs recirculation mode) treated 32.3±2.5 m^3d^{-1} of domestic wastewater achieving up to 92±5% of COD removal. During the 2nd period of operation, the system operated without recirculation between the 2 different types of vertical flow wetlands and under an influent flow of 65±4.0 m^3d^{-1} of domestic wastewater and achieved up to 96±1% of COD removal

Keywords: UASB, constructed wetlands, domestic wastewater treatment

1. Introduction

During the last decades, different wastewater treatment technologies have been applied in remote areas characterized by high seasonal variability of wastewater flow.

Such areas are usually adopting the conventional activated sludge process. The activated sludge process is being criticized as an energy intensive process. Remote areas in the Mediterranean are often not able to cope with the burden of the operating expenses of this system. Recent studies are focusing in the application of other processes that offer higher performance and simplicity in terms of operation and maintenance and which can also recover resources (Ruiz et al., 2008; Singh et al., 2015).

The anaerobic processes are an attractive prospect for small, decentralized areas since they can achieve sufficient treatment performance under low operational costs having the advantage of energy production in the form of biogas (Capodaglio et al., 2017). The anaerobic technology that can be applied for domestic wastewater treatment is the upflow sludge blanket (UASB) reactor.

The UASB technology offers sufficient COD removal even under moderate temperatures, while at the same time biogas is produced. The main disadvantage of this technology is that this process is unable to reach the treated effluent discharge limits of developed countries, mainly due to the inability of the anaerobic bacteria to reduce the nutrient content of wastewater and due to its lower capacity to remove organic matter and suspended solids (Engida et al., 2020).

In order to overcome the limited performance of the UASB technology in meeting strict effluent standards, an efficient strategy is to combine the UASB with technologies that are able to further reduce the organic content of the wastewater and at the same time remove nutrients (Tufaner, 2020).

A wastewater treatment technology that offers simplicity in operation and is able to achieve high performance when used as a secondary treatment process after a UASB reactor, is the nature based solution (NBS) of constructed wetlands (CWs). The application of CWs after UASB process eliminates the problems of clogging in the wetlands while this combination of technologies offers high performance in terms of organic carbon, suspended solids, nutrients and pathogens removal (Ruiz et al., 2008).

The aim of this work is to present an integrated, full-scale system that combines UASB and constructed wetlands in order to treat domestic wastewater in a remote, water scarce area and with the addition of UV disinfection to produce treated wastewater suitable for unrestricted agricultural irrigation.

2. Materials and Methods

2.1. UASB- Vertical flow Constructed wetlands

UASB reactors

The core of the anaerobic unit consists of two identical square base UASB reactors made of steel. The volume of each reactor is 24 m^3 and the two tanks can operate either hydraulically independently or connected to each other.

The other major parts of the anaerobic systems consist of a 2.15 m^3 equalization tank, which is equipped with a resistance in order to control the raw wastewater temperature and a 2.94 m^3 clarifier tank that is used for the collection of the two UASB effluent streams as well as for the recirculation process. A double membrane gasometer with a volume of 10 m^3 is also integrated in order to collect the produced biogas. Furthermore, the unit is equipped with four pumps for the feeding and recirculation process, a number of pneumatic valves and a variety of quantitative and qualitative online sensors. The anaerobic unit is fully automated and is controlled by a programmable logic controller (PLC).

Constructed wetland units

The nature-based system of constructed wetlands (CWs) consists of a combination of vertical subsurface flow units that can treat up to 100 m^3/d of primary treated effluent. The first stage of the CWs includes a saturated down-flow wetland while the second stage consists of 4 distinct lines of unsaturated intermitted load CWs. The CW unit also includes a pumping station with 2 submerged pumps that are used for the pumping of the saturated CW effluent to the unsaturated CW units and a recirculation and by-pass manhole that allows the implementation of different configurations of operation. The operation of the CWs is fully automated and controlled by a PLC while many different online probes are installed at different stages of the system in order to provide real time measurements of the process.

Start-up and operation

The start-up of the UASB reactors was held with the inoculation of each reactor with 5 m^3 of anaerobic sludge originating from an anaerobic reactor of a potato industry. The reactors were filled up to their maximum active volume with treated wastewater from a conventional wastewater treatment plant and the operation started with an initial feed of 8 m^3/d of raw wastewater to each UASB. The operational characteristics of the UASB-CW systems are shown in Table 1 for each period.

After two weeks of UASB operation the CWs were also put into operation. The first period of operation aimed to the gradual stabilization of the constructed wetlands and the enhancement of the reed plant growth.

Table 1. Operational characteristics of the UASB-CWs system

Parameter	Start-up	1st period	2nd period
Q_{in} (m^3 d^{-1})	15.9±1.0	32.3±2.5	65±4.0
Temperature (°C)	21.1±2.5	25.4±1.7	27.1±0.9
*HRT (h)	61.8±4.6	30.7±2.8	15.0±1.0
*Upflow velocity (m h^{-1})	0.28±0.05	0.30±0.02	0.30±0.03
*OLR_{UASB} (kg COD m^{-3} d^{-1})	0.14±0.05	0.46±0.15	1.18±0.27

**Refers to the sum of the two UASB reactors*

Daily monitoring analysis

The UASB-CW unit performance was evaluated by routine measurements of chemical oxygen demand (COD), ammonium (NH_4^+-N), nitrate (NO_3^--N), phosphate (PO_4^{-3}-P), total suspended solids (TSS) and volatile suspended solids (VSS). All analyses were performed according to the Standard Methods (APHA, 2012).

3. Results and discussion

During the first months of operation, the UASB reactor performance was gradually stabilized in terms of TSS and COD removal. Due to the slow growth rates of the anaerobic sludge as well as the low temperatures during the start-up period, the UASB units operated under a low OLR and high HRT for 3 months after the inoculation.

After the start-up period, the UASB-CWs operated under two distinct periods that differ regarding the operational characteristics. More specifically, from days 89-118 (1st period) the unit operated under an influent flow rate of 32.3±2.5m^3 d^{-1} of domestic wastewater while the CWs operated under recirculation modes between the saturated and unsaturated VF wetlands. During days 119-145 (2nd period), the influent flow was increased to 65±4.0 m^3 d^{-1} while the CWs operated without any internal recirculation.

Figure 1 and Figure 2 present the TSS and COD concentration respectively in the influent wastewater, in the UASB effluent as well as in the CWs effluent which is the final effluent of the system. During the start-up of the UASB-CWs system, the UASB achieved a TSS removal of 45±20% while the COD removal was up to 32±16% indicating a rather low performance of the anaerobic reactors. Despite the low organic loading rate of 0.14±0.05 kg COD m^3 d^{-1}, the UASB reactors underperformed mainly due to the low temperatures of this period (<18 °C) and the time needed for the stabilization of the inoculated sludge to the different conditions. After the first 3 months of operation, the anaerobic sludge was gradually acclimated and the UASB efficiency improved; specifically, the average COD in the UASB effluent decreased from 298±97 during the start-up to 214±47 mg COD L^{-1} during the 1^{st} period. Throughout this operation period, the performance of the CWs system was quite stable, achieving more than 83% of COD removal. The total COD removal of the integrated UASB-CWs was equal to 92±5 mg L^{-1} and up to 97% of ammonium nitrogen removal. During the 2^{nd} period, even though the influent wastewater flow increased to 67.2 m^3 d^{-1}, the performance of the UASB-CWs system remained quite stable with the TSS and COD concentrations in the final effluent lower than 3 mg L^{-1} and 35 mg L^{-1} respectively. At the same period, the NH_4-N removal was up to 97.2±2%, indicating the efficient performance of constructed wetlands with respect to ammonia removal.

4. Conclusion

This work examined the start-up and the first period of stable performance of a full scale UASB-vertical flow constructed wetland system for domestic wastewater treatment. The start-up period lasted 3 months before a stable and efficient performance of the system was achieved. The initial results of the UASB-CWs unit indicated that the combination of UASB with NBS such as constructed wetlands can offer high performance with respect to COD, TSS and ammonia removal that can meet the strict Greek standards for irrigation and Class A agricultural wastewater reuse guidelines (EU, 2020/741).

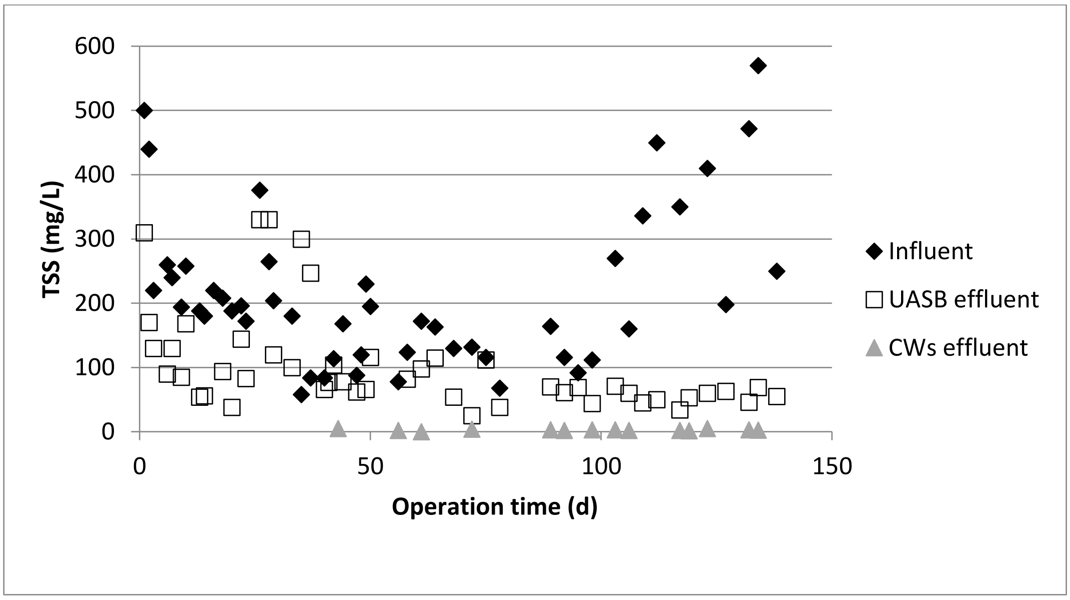

Figure 1. TSS concentration in the domestic wastewater, the UASB effluent and at the CWs effluent

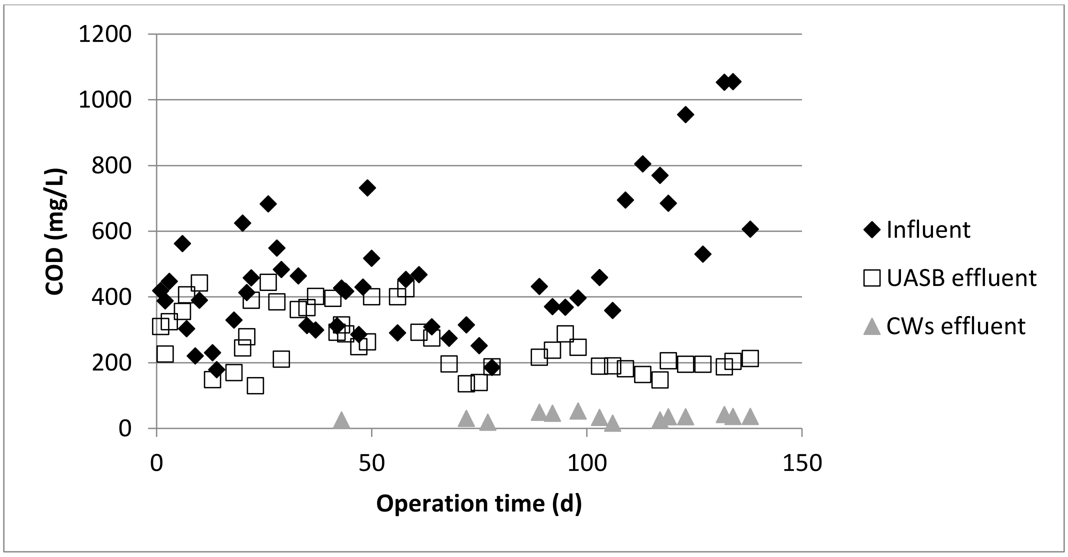

Figure 2. COD concentration in the domestic wastewater, the UASB effluent and at the CWs effluent

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