Separation of solids and disinfection for agronomical use of the effluent from a UASB reactor


ABSTRACT

The present work addresses the preparation of the effluent from a full-scale upflow anaerobic sludge blanket (UASB) reactor for drip irrigation of orange crops. The pilot plant included a lamella plate clarifier followed by a geo-textile blanket filter and a UV disinfection reactor. The clarifier operated with a surface load of 115 m³ m⁻² d⁻¹, whereas the filter operated with 10 m³ m⁻² d⁻¹. The UV reactor was an open-channel type and the effective dose was approximately 2.8 W h m⁻³. The effluent of the UASB reactor received 0.5 mg L⁻¹ cationic polyelectrolyte before entering the high-rate clarifier. Suspended solids' concentrations and Escherichia coli and helminth egg's densities were monitored throughout the treatment system for 12 months. Results showed that the total suspended solids concentration in the filter effluent was lower than 7 mg L⁻¹ and helminth density was below 1.0 egg L⁻¹. The UV disinfection demonstrated the ability to produce a final effluent with E. coli density lower than 10³ MPN/100 mL (MPN: most probable number) during the entire process. Thus, the World Health Organization standards for unrestricted crop use were met. Agronomic interest parameters were controlled and it was possible to identify the important contribution of treated sewage in terms of the main nutrients.

Key words | geo-textile blanket filter, lamella plate clarifier, UASB reactor, ultraviolet disinfection

INTRODUCTION

The use of treated wastewater for irrigation of agricultural crops reaches one tenth of the world's population. It is a practice of relevant significance for both the preservation of natural water resources and for the use of nutrients found in the effluent. The latter is of particular importance due to the subsequent decrease in the demand for chemical fertilizers in agriculture (Carr 2005). As described by Bixio et al. (2006), in southwest Europe, the predominant reuse of water for agricultural purposes occurs in 44% of the projects already implemented, and 37% of the reuse occurs in urban areas. In northwestern Europe, 51% of the reused water is utilized for urban purposes and 33% for industrial purposes. The majority of medium- to large-sized plants operates with secondary treatment systems to achieve unrestricted irrigation standards. For example, the conventional secondary treatment system requires complementation, which is done in accordance with the desired quality of the effluent. Typically, filtration is used in its many variations, followed by disinfection. Disinfection is generally accomplished by chlorination. However, a trend for ultraviolet radiation has been observed (Bixio et al. 2006). In Mezquital Valley, Mexico, 76.119 ha for food production are irrigated with treated sewage effluent representing the subsidy of 195 kg ha⁻¹ nitrogen and phosphorus 81 kg ha⁻¹, an important source of these resources for the region (Jimenez & Takashi 2005). In most developing countries, there is a need for further research to guide the regulation of water reuse in agriculture, as suggested by WHO (2006). Epidemiological studies on the impact of treated sewage reuse must be carefully considered to provide enough protection for each water reuse situation. For example, an epidemiological study in Central Mexico, where the proposed value was measured as helminths, might not promote enough protection in hot climates and moist soil conditions, which are favorable for the survival of eggs, thereby allowing the accumulation of viable eggs in the soil (Jimenez 2007; Navarro et al. 2009).

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In hot climate countries, upflow anaerobic sludge blanket (UASB) reactors are effective for the removal of 60–75% of organic matter, but not for the removal of nutrients such as nitrogen and phosphorus. Interestingly, this effluent can be used in agriculture as a source of fertilizer. However, it is necessary to remove colloidal and suspended material from the effluent of the UASB reactors, whose typical values range from 50 to 100 mg L\(^{-1}\) of total suspended solids (TSS), since high TSS concentrations impair the action of disinfecting agents. The use of UASB reactor effluent polishing systems based on the removal of solids leads to two relevant results: (1) it promotes the possibility of effective disinfection of the effluent in terms of coliforms, and (2) it creates the possibility of removing parasites from the effluent (Van Haandel & Lettinga 1994).

**METHODS**

The present study was conducted in the premises of the wastewater treatment plant (WWTP) for domestic sewage in the city of Piracicaba (Southeast Brazil). The WWTP consists of preliminary treatment with a 3 mm screening and a grit chamber, followed by UASB reactors. The UASB reactors were operated receiving the average flow rate of 219 L s\(^{-1}\), with a hydraulic retention time of 13.6 h, with regular removal of excess sludge. The average air temperature was 24\(^\circ\)C and the temperature measured in the liquid effluent was about 20 to 25 \(^\circ\)C.

The system proposed in this work promotes the removal of suspended solids, remnants of the UASB, and improves disinfection to obtain the production of a liquid effluent which is safe for both irrigation and the health of the farming community. The effluent was applied to the orange crop in the area adjacent to the WWTP by the agricultural research project team (NUPEGEL-ESALQ-USP).

A flow rate of 2 m\(^3\) h\(^{-1}\) was drawn from the effluent of the UASB reactors to feed the post-treatment pilot system consisting of three units, namely: lamella plate clarifier, followed by geo-textile nonwoven filter, and a reactor for disinfection by ultraviolet radiation (UV) (Figure 1). The use of a clarifier for high hydraulic surface load is a practice that has been given more attention in recent years in the field of wastewater treatment. Even though the lamella plate clarifier occupies significantly smaller areas when compared to conventional clarifiers, the lack of practical knowledge in its operation, associated with the various types of biological treatment, still creates limitations for its use. Filtration by a nonwoven geo-textile blanket was included to assess the effects of removing solids in the UV disinfection process. Additionally, the blanket filtration process provides operational simplicity and great potential economic benefits. Disinfection by ultraviolet radiation was chosen primarily for its practicality and to avoid introducing chemical species in the irrigation effluent that is applied to field crops.

The lamella plate clarifier was operated with a hydraulic surface load of 115 m\(^3\) m\(^{-2}\) d\(^{-1}\), built with parallel plates 1.0 m long, 6 cm apart from each other, with a 60\(^\circ\) inclination. The cationic polymer solution was added with a flow rate of 2.5 L h\(^{-1}\) to the clarifier effluent, resulting in a dosage of 0.5 mg L\(^{-1}\). The geo-textile blanket filter was operated with a hydraulic surface load of 10 m\(^3\) m\(^{-2}\) d\(^{-1}\), built with a surface area of 4.0 m\(^2\). The blanket support material was composed of crushed stones with 5 cm diameter in layers of 30 cm, and the blanket’s water depth layer was 15 cm. The nonwoven geo-textile blanket weighed
130 g m⁻² and had an average 160 μm mesh size. Since this material is widely used in soil and slope stabilization and drainage systems, no additional product information is provided. Germicidal lamps, with a rated power of 15 W and low-pressure mercury vapor, were used in the UV reactor. The power available for UV-C radiation is 4.9 W, as described by the manufacturer. The lamps were built in a stainless steel structure with an aluminum lid. The lamps were installed emerged and operated in cross flow. The water level was 4 cm, controlled by a weir, and the exposure time was 20 s. The average dose achieved for the effluent of the post-treatment exhaust was 2.44 Wh m⁻³ with a total of five lamps.

The operational control was accomplished with the UASB reactors' influent and effluent sampling to characterize the WWTP. Sampling was performed in the pilot system on the clarifier effluent, on the effluent from the filter, and on the UV reactor effluent. The characterization of the physicochemical effluents was achieved through chemical oxygen demand (COD), TSS, λ = 254 nm absorbance (ABS), and turbidity (T), in accordance with Standard Methods for the Examination of Water and Wastewater (APHA 1998). Microbiologic characterization was completed with Escherichia coli count by the Colilert Chromogenic method at 35 °C. Finally, the parasitological characterization was accomplished by helminth eggs count using the Bailenger method, modified and applied by different authors (Ayres & Mara 1996; Cutolo et al. 2006; Piveli et al. 2011).

RESULTS AND DISCUSSION

Table 1 shows the results of the physicochemical tests. The UASB reactors influent had an average COD of 362 mg L⁻¹. The organic loading rate applied to the UASB was 0.63 kgCOD m⁻³ d⁻¹. The UASB reactors showed a COD removal efficiency of 58% with an effluent COD of 150 mg L⁻¹. The UASB reactors' effluents showed average values of TSS concentration, absorbance, and turbidity of 86 mg L⁻¹, 0.59 cm⁻¹, and 56.8 NTU, respectively.

According to Table 1, the effluent from the geo-textile filter showed the average TSS concentration of 7 mg L⁻¹, with values between 1 and 25 mg L⁻¹. The effluent from the clarifier showed an average of 55 mg L⁻¹ TSS. The TSS removal by the clarifier showed an efficiency of 36%, while the geo-textile blanket filter obtained a TSS removal efficiency of 87%. The TSS removal efficiency from UASB reactors' effluents by the clarifier-filter system was 92%. Figure 2 shows the historical series of TSS in the raw sewage and effluents from the UASB reactors, clarifier, and filter. The TSS concentrations found on the clarifier effluent are too high to apply UV radiation for its disinfection, being significantly higher than 10 mg/L (Loge et al. 1996). Although the clarifier removed a lower amount of TSS, when compared to the geo-textile blanket, it is able to reduce to some extent the quantity of solids entering the filter, as shown in Figure 2. It was found that there were three distinct groups of TSS values for the UASB reactor effluent, which were: (1) values between 50 and 70 mg L⁻¹, (2) values between 70 and 100 mg L⁻¹, and (3) values above 100 mg L⁻¹. The results showed the TSS removal efficiency of the UASB reactor effluent by the lamella plate clarifier for group (1) was between 18 and 55%, for group (2) between 21 and 52% and for group (3) between 42 and 64%, respectively. There was an isolated result obtained in group (3) which showed a TSS removal efficiency of 15%. That is, the clarifier can function as a regulator of the solids entering the filter, since the UASB reactor's effluent did not present a consistent concentration of suspended solids.

During the study, the geo-textile blanket filter operated for 1 hour per day. The geo-textile blanket was replaced periodically once every three months to maintain the effluent with a TSS concentration of 10 mg L⁻¹ or lower. The suspended solids’ concentration in the filter effluent was

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<td>Avg</td>
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<tr>
<td>COD mg L⁻¹</td>
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<td>362</td>
<td>102</td>
<td>22</td>
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<td>146</td>
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<td>ABS cm⁻¹</td>
<td>21</td>
<td>1.09</td>
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<td>Turbidity NTU</td>
<td>21</td>
<td>97.4</td>
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n – number of samples; Avg – average; sd – standard deviation.
lower than 10 mg L$^{-1}$ for an applied solids’ mass of 1.43 kg m$^{-2}$ and lower. Values of solids’ application rate greater than 1.43 kg m$^{-2}$ exhibited a gradual increase in TSS concentrations as shown in Figure 3. Starting with the next value of applied solids’ mass, 2.05 kg TSS m$^{-2}$, the effluents’ TSS concentration increased from 14.78 to 35.0 mg L$^{-1}$, for an application rate of 3.50 kg TSS m$^{-2}$, at the end of the experiment. This was equivalent to 298.25 m$^{3}$ of filtered effluent. The capital cost of the geo-textile blanket was USD$0.16/person, considering the need of backwash cleaning for the system’s continuous operation. Backwash cleaning for the blanket would occur every 3.84 days, which represents operational simplicity when compared to a conventional filter.

The turbidity of the effluent from the UASB reactors was 56.8 NTU, while the clarifier produced an effluent with 52.1 NTU. The effluent of the geo-textile blanket filter showed an 11.2 NTU turbidity, representing a removal efficiency of 80%. The absorbance rates of the clarifier effluent were always lower than those of the UASB reactors, although numerically close. The absorbance of the clarifier effluent was 11% lower than its influent. The average clarifier effluent absorbance was equal to 0.528 cm$^{-1}$, comprised between 0.355 and 0.767 cm$^{-1}$. The effluent from the geo-textile filter had an average absorbance of 0.245 cm$^{-1}$, 52% lower than the value of its tributary. The dispersion was fairly small with a standard deviation of 0.010 cm$^{-1}$, with values ranging between 0.161 and 0.346 cm$^{-1}$. The process unit comprising the lamella plate clarifier and the geo-textile filter reached an average 59% decrease in absorbance. Bilotta & Daniel (2010) conducted tests with effluent from UASB reactors subjected to a biological filter with activated carbon, reaching an effluent with absorbance of 0.298 cm$^{-1}$. Tessele et al. (2011) reached an effluent with absorbance of around 0.1 cm$^{-1}$ by using a UASB reactor with a flotation post-treatment for TSS removal, and a coagulation process with ferric chloride, followed by a secondary flotation process to remove phosphates.

The radiation intensity measured on the liquid sheet surface through ray-meter was 1.89 mW cm$^{-2}$. The average UV radiation dose employed per volume of the geo-textile filter’s effluent, 2.44 W h m$^{-3}$, was obtained from the applied dose of UV radiation, the absorbance values acquired from previous results, the reactor flow, and the exposure time of the effluent. The lamella plate clarifier effluent had a mean absorbance value of 0.51 cm$^{-1}$, which resulted in a UV radiation dose of 1.25 W h m$^{-3}$.

The microbiological results showed average values of 7.26 × 10$^3$/100 mL of $E. coli$ in the raw sewage and 3.71 × 10$^2$/100 mL in the effluent submitted to filtration followed by disinfection. The minimum and maximum values of $E. coli$ observed in the effluent of UASB reactor were 3.50 × 10$^2$/100 mL and 2.70 × 10$^3$/100 mL, respectively. In the filtered, disinfected effluent the $E. coli$ values reached between 1.00 × 10$^1$/100 mL and 3.42 × 10$^1$/100 mL. Figure 4 shows the time series of the $E. coli$ system for all treatment and post-treatment units. The evolution of $E. coli$ removal
along the different stages of the system is shown in this figure. The WHO guidelines (WHO 2006) propose a new approach based on risk evaluation allowing $\leq 10^3$ E. coli/100 mL for unrestricted irrigation and $\leq 10^5$ E. coli/100 mL for restricted irrigation with the additional limitations, such as crop cleaning bacteria die-off (Lazarova & Bahri 2008). The average density of $10^2$ E. coli/100 mL was reached in the effluent of UASB reactors entering the lamella plate clarifier and the geo-textile filter disinfected with UV radiation. This average density showed values ranging from 0 to $10^3$ E. coli/100 mL, which allows for reusing the effluent in orange crops. A density of $4.6 \times 10^{-3}$/100 mL E. coli can be considered a medium risk for rotavirus infection from consumption of wastewater-irrigated lettuce according to 10,000 Monte Carlo simulations based on the model of Karavarsamis & Hamilton (2010). However, WHO guidelines establish $3.5 \times 10^{-3}$/100 mL as the medium risk (2006) for estimating the annual rotavirus infection risks from the consumption of wastewater-irrigated lettuce by 10,000 Monte Carlo simulations (Mara et al. 2010). The logN/N0 ratio was developed and shown in Figure 5. There was a strong correlation between the reduced E. coli density with the UV dose variation, with the correlation coefficient being $r = 0.79$ ($r^2 = 0.62$). The UV dose received varied according to the variation of the effluent quality. However, the power applied to the UV radiation was constant throughout the entire study. The reduction of 3 logs of E. coli was achieved with the UV dose received of 2.0 W h m$^{-3}$, with the effluent retaining its lower than 20 mg L$^{-1}$ TSS concentration, and absorbance lower than 0.5 cm$^{-1}$.

Coletti (2003) performed tests for UV disinfection for secondary effluents and the same logN/N0 ratio. He found a diminution ratio of 3 or more E. coli log units with the UV dose starting from 2.0 W h m$^{-3}$. Keller et al. (2004) obtained similar results, reaching a 3 log reduction of E. coli with a UV dose received of 2.07 W h m$^{-3}$ in a tertiary effluent. The same author attained the removal of 4 logs E. coli with the dose of 3.47 W h m$^{-3}$. Bilotta & Daniel (2010) tested the UV disinfection of the effluent from the UASB reactor followed by a trickling filter and reduced the E. coli density from $10^6$ to $10^2$. Tessele et al. (2011) showed a decrease of E. coli from $10^5$ to approximately $10^4$ MPN/100 mL (MPN: most probable number) by applying the UV dose of 25 mj cm$^{-2}$ and with an effluent absorbance of 0.1 cm$^{-1}$.

The count of helminth eggs resulted in mean values of 1.28 eggs L$^{-1}$ in the raw sewage, 1.19 eggs L$^{-1}$ in the effluent from the UASB reactors, and 0.89 egg L$^{-1}$ in the effluent of the post-treatment and disinfection units. The post-treatment removed 50% of helminth eggs in the UASB effluent. The WHO recommends a maximum helminth eggs value of 0.89 egg L$^{-1}$ (WHO 2006), which is less than 1.0 egg L$^{-1}$. Piveli et al. (2011) showed permissible values of helminth eggs of 1.03 eggs L$^{-1}$ (2.19 eggs L$^{-1}$) in wastewater from UASB reactors and 0.92 egg L$^{-1}$ (1.88 eggs L$^{-1}$) in pilot systems with a sand filter followed by a clarifier. The filtered and disinfected effluent showed an average turbidity of 11.2 NTU. If the turbidity present has a value of $\leq 2$ NTU, the evaluation of helminth eggs could be dispensed (WHO 2006). In case children are exposed to the effluent ($\leq 15$ years), the recommended standard is $\leq 0.1$ egg L$^{-1}$ and more demanding additional measures such as the use of personal protective equipment and treatment chemotherapy (WHO 2006). Throughout the analysis, the presence of Ascaris sp. was verified as indicators in the samples, as cited by Seidu et al. (2006), Navarro et al. (2009), and Mara (2011). Ascariasis is a common disease in developing countries and is endemic in Africa (Seidu et al. 2006), Mexico (Navarro et al. 2009) and Brazil (Cutolo et al. 2006).

![Figure 5](https://iwaponline.com/wst/article-pdf/69/1/25/471806/25.pdf)  
**Figure 5** LogN/N0 x UV dose received in the effluent of the clarifier and filter.

**CONCLUSIONS**

The post-treatment process presented in this work for the UASB reactors’ effluent consists of a lamella plate clarifier followed by geo-textile filter. The scheme demonstrated the efficiency of the entire process, where the clarifier removed part of the suspended solids in the UASB reactors’ effluent, thus minimizing its accumulation in the filtration stage. The filter achieved a good result in the final disinfection by ultraviolet radiation, measured by the decreased E. coli density. The presented results also showed positive aspects in the post-treatment units by increasing the removal COD and
helminth eggs and reducing the clogging in the drip irrigation system that often originates from the TSS in the effluent.

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