Pathogen removal efficiency from UASB + BF effluent using conventional and UV post-treatment systems

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Water Science and Technology **Vol 50 No 1 pp 1–6**

Abstract The aim of this study was to verify the efficiency of removal of microorganisms in effluents of a Wastewater Treatment Plant (WWTP) comprising an association of a UASB reactor followed by three submerged aerated biofilters (BAF) and one tertiary filter. The WWTP designed to treat domestic wastewater from a population of 1,000 inhabitants showed high removal efficiency for organic matter and suspended solids. Helminth eggs were also efficiently removed from the tertiary effluent and were found in the sludge from the UASB reactor; however, removal of bacteria in this system was very low. To enhance the efficiency of the system, the effluent from tertiary filters was submitted to UV disinfection in a real scale reactor. Our results showed that UV irradiation was very effective at lowering the concentrations of *E. coli*, thermotolerant coliforms and coliphages to acceptable levels for agricultural reuse. *Salmonella* spp. and helminth eggs were seeded into the tertiary effluent before passing through the UV reactor. *Salmonella* was not found in the final effluent, but helminth eggs were not completely inactivated by UV irradiation and viable eggs were detected after 28 d of incubation.

Keywords Coliphages; *E. coli*; thermotolerant coliforms; UV disinfection; wastewater

Introduction

Despite technological advances in water and wastewater treatments, contaminated water is still an important vehicle of transmission for enteric pathogens of humans and animals. Untreated waters are normally discharged into surface waters. This is especially true in undeveloped countries, where gastroenteritis is a major contributor to morbidity and mortality of children under five years old. In Brazil, the official health authorities have indicated that 90% of children are exposed to diarrhoeal infection and waterborne diseases, while <10% of the population has the full benefit of sanitation systems. Untreated waters have been used in some countries for irrigation activities without previous treatment. Additionally, many agricultural areas have been irrigated with surface water with levels of thermotolerant coliforms above that recommended by OMS.

Alternatives to improve wastewater treatment have been proposed. The technology UASB + BF (upflow anaerobic sludge bioreactor plus biofilter) has been shown to be very interesting for tropical and sub-tropical areas, due to low production of stabilised sludge and better effluent quality with efficiency of 88% and 85% for SS and COD removal respectively. Gonçalves *et al.* (1997, 1998) and Bof (1999) evaluated the performance of this system and showed that this association was very effective at removing TSS, BOD and COD. However, the assembly did not produce a bacteriologically safe effluent. Alternative methods, such as UV irradiation, have been proposed for disinfection of water and wastewater after conventional treatment. This study aimed to verify the efficiency of UV irradiation for the inactivation of thermotolerant coliforms, *E. coli, Salmonella* spp. and coliphages in treated wastewater exposed to increasing doses of UV irradiation.

Materials and methods

Pilot-plant description

The study was carried out at the Wastewater Treatment Plant (WWTP) situated at the Federal University of Espirito Santo (UFES, Brazil) receiving domestic sewage with average characteristics from a residential urban area of Vitória (south-east Brazil). The WWTP (capacity 2 L/s domestic sewage) comprised a single UASB reactor (35 m^3), three secondary submerged aerated biofilters (12 m^3) and one tertiary filter associated in series (Gonçalves *et al.*, 2002). This configuration was able to produce <5NTU effluent, allowing easier UV disinfection (Figure 1). The wastewater samples were taken once a week over three months.

UV irradiation experiments

Laboratory scale. Samples from raw sewage and effluents from primary treatment (UASB), secondary treatment (BF2) and tertiary treatment (tertiary BF) were used in the irradiation experiments. Control non-irradiated samples were also taken. The irradiation experiments were performed in a batch reactor that consisted of a low-pressure germicidal lamp suspended 40 cm above the exposure area. Collimated radiation was measured with a radiometer (MOD.UVC 254-COD.2056, Lutron Instruments) using a detector for incident intensity at 254 nm wavelength. UV doses of 10, 20, 30, 50, 75 and 100 $mWsec/cm^2$ were applied to the samples collected from the WWTP. After irradiation, samples were analysed for the presence of thermotolerant coliforms, *E. coli* and coliphages. *Salmonella* spp. obtained from clinical isolates (6×10^5) was seeded into beakers with 120 mL autoclaved effluents and also irradiated.

Real scale. Experiments were performed in a compact UV reactor of emerged lamps. Low-pressure mercury UV lamps (×26; 30 W; spaced 10 cm from each other) were transversely positioned to the flow of liquid. The reactor continually received the effluent from tertiary treatment. For real-scale experiments, once a week and over five weeks, simple samples were collected at five points in the UV reactor, to measure the decay of coliforms, *E. coli* and coliphages present in the tertiary effluent. The applied dose was estimated from the product of the hydraulic retention time and the median intensity in the reactor. Experiments with *Salmonella* spp and helminth eggs were also carried out once a week over five weeks. *Salmonella* (1×10^6 cells) and helminth eggs (16 eggs/L) were seeded into a 310 L box with

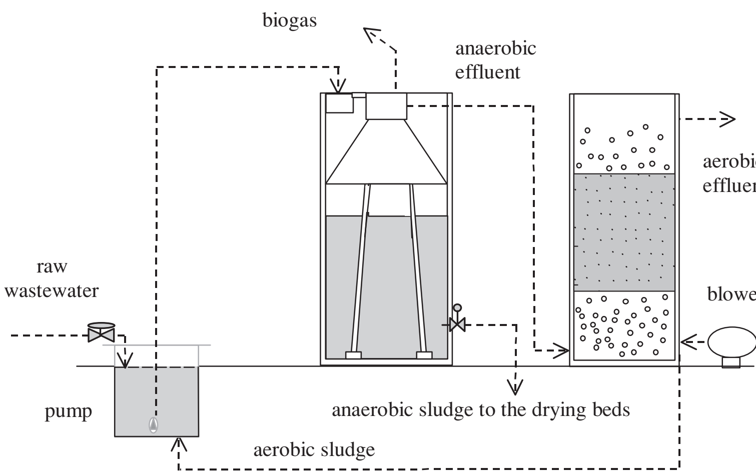


Figure 1 Flow diagram of the UFES WWTP

tertiary effluent from the WWTP. The artificially contaminated effluent was allowed to flow for 10 min in the reactor and samples were collected at the beginning, the middle and at the end of the reactor. To avoid any contamination of the water bodies, 5% chlorine was added to eliminate microorganisms not inactivated by UV irradiation during the tests.

Microbiological analyses

To evaluate the efficiency of removal of microorganisms from the WWTP, only thermotolerant coliforms and helminth eggs were monitored once a week for three months. The density of thermotolerant coliforms was estimated by MPN (APHA, 1995) using culture medium A1. *E. coli* was quantified by MPN using Fluorocult–LMX-ReadyCult as culture medium (APHA, 1995). Salmonellae were obtained from clinical samples and cultured in selective selenite medium with novobiocin antibiotic for 24 h followed by culture on XLD or Brilliant Green agars with the MPN determined after 24 h (CETESB, 1993). Coliphages were analysed by the method described by CETESB (1990) using E. coli C (ATCC 13706) as host. The number of helminth eggs was estimated by the Meyer technique (Meyer, 1975), and the viability of *Ascaris lumbricoides* was determined using the incubation technique.

Physicochemical parameters

Physicochemical analyses were performed according to *Standard Methods* (APHA, 1995). The parameters analysed were (a) absorbance at 254 nm (Ultrospec 1000 UV spectrophotometer, Amersham) using a quartz cuvette with 1 cm path length with deionised water as a blank, (b) turbidity (NTU) (Lamotte, mod 2020), (c) COD and (d) total suspended solids (TSS).

Results and discussion

Wastewater treatment plant performance

The average values obtained from the monitoring of the plant indicated COD = 499 mg/L and TSS = 168 mg/L for raw sewage (Table 1). The UASB reactor achieved 62% removal of organic matter (COD = 191 mg/L; TSS = 62 mg/L) from primary effluent decreasing the organic matter affluent in the aerobic reactor, minimising costs due to energy consumption with aeration. The final effluent achieved TSS <30 mg/L and COD <90 mg/L with removal efficiency of 78% of the carbonaceous substrate. As a result, the reactors may have smaller volumes, maintaining the same effluent quality. The bottom sludge showed a concentration of 5% of total solids (θ = 11 h). Although the returned sludge from the biofilters had a VS concentration of 80%, the combined sludge kept the VS concentration at 59%. Sludge production in the biofilters was estimated in 1.44 kg TSS/d, while the UASB reactor presented a sludge production rate of 2.29 kg TSS/d. The biogas was produced at 190 $L_{biogas}kgCOD_{rem}$ equivalent to 7 L/inhab/d. Considering that 70% of the biogas is formed by methane and admitting a 30% energy utilisation efficiency, methane production of 1.3 kg CH_4/d generated an amount of energy of 0.23 KW/d (5W/inhab/day).

Table 1 Overall performance of the UASB + BAF system (50 samples)

	Mean (standard deviation) mg/L			
	TSS	COD	COD filtered	BOD
Raw wastewater	168 (63)	499 (369)	194 (51)	187 (85)
UASB	62 (18)	191 (45)	99 (26)	57 (31)
Biofilters	23 (14)	78 (36)	52 (18)	26 (19)

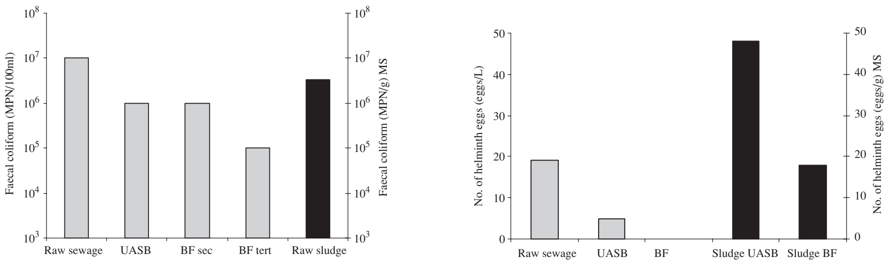
Removal of microorganisms in the WWTP

To verify the efficiency of removal of thermotolerant coliforms in the association UASB + BF, the density of these microorganisms was determined in the raw wastewater, effluents of UASB, BF1, BF2, BF3 and tertiary effluent. For raw sewage thermotolerant coliforms levels were $2.4 \times 10^6 - 5.0 \times 10^7$ MPM/100 mL (geometric mean 1.0×10^7/100 mL). The UASB effluent gave levels of $1.0 \times 10^5 - 1.3 \times 10^7$ MPN/100 mL (geometric mean 2.0×10^6/100mL) showing a 1-log removal efficiency. For BF1 and BF2 the average was 4.1×10^5 MPN/100 mL and 5.4×10^5 MPN/100 mL respectively. The effluent from BF3 showed densities of $3.0 \times 10^4 - 3.0 \times 10^6$ MPN/100 mL (geometric mean 1.3×10^6/100 mL) showing that BF3 did not remove thermotolerant coliforms from the effluent. Levels of coliforms from tertiary biofilter effluent showed large variations ($3.0 \times 10^4 - 5.0 \times 10^6$ MPN/100 mL, geometric mean 9.3×10^5 MPN/100 mL). Overall, the association UASB + BF gave an efficiency of 2-log removal of thermotolerant coliforms (Figure 2a).

The results of detection of helminth eggs in samples from raw sewage, UASB and BF effluents are presented in Figure 2b. In raw sewage the number of helminth eggs detected varied (16.7–33.3 eggs/L) with an average of 19.5 eggs/L). In the UASB effluent the average was 5 eggs/L with 62% removal. In both effluents *Ascaris lumbricoides* was the most prevalent helminth.

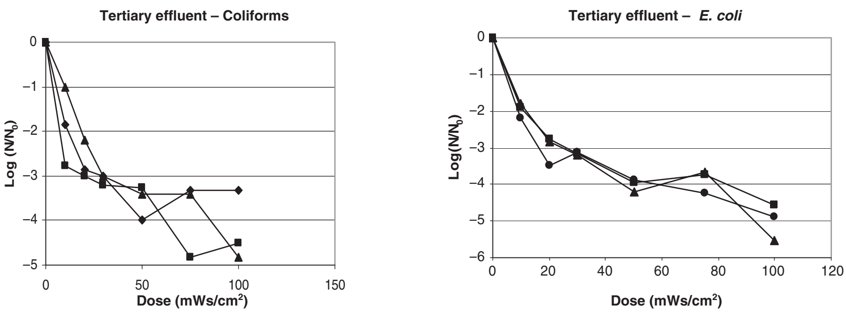
UV irradiation studies

Laboratory scale. The high densities of coliforms found in the tertiary effluent showed that it was necessary to improve the quality of the final effluent of UASB + BF to attain the WHO recommendation for reuse of the effluent. Laboratory-scale experiments using UV irradiation were done to verify to performance of this method to reduce coliforms and other microorganisms in the tertiary effluent.



(a) (b)

Figure 2 Thermotolerant coliform density (a), and helminth egg counts (b), detected in the liquid phase and in the solid phase of the treatment at WWTP



(a) (b)

Figure 3 Inactivation of coliforms (a) and *E. coli* (b) present in the tertiary effluent after increasing doses of UV irradiation

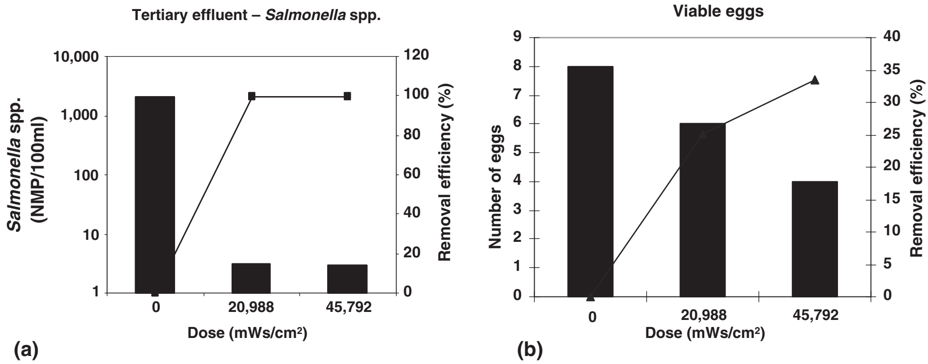


Figure 4 Removal of *Salmonella* spp. (a) and helminth eggs (b) after increasing doses of UV irradiation at three points in the UV reactor

Our results showed that the number of microorganisms present in treated wastewater effluents could be considerably reduced after UV disinfection. In raw wastewater and UASB effluent from the WWTP the inactivation of coliforms was not significant, indicating that the quantity of suspended solids was an important obstacle to UV penetration in bacteria. However, samples from effluents of secondary and tertiary treatment had lower quantities of suspended solids and presented better results of inactivation after irradiation.

The inactivation curve showed a resistant tail after 2-log reduction. This tail may have been caused by the presence of a resistant sub-population of bacteria or by the presence of suspended solids. This behaviour was also obtained in experiments with *E. coli, Salmonella* spp. and coliphages, indicating that they were affected in a similar way by the UV irradiation (not shown).

Studies with helminth eggs seeded on tertiary effluent before passing through the UV reactor showed that samples collected at the end of the reactor and analysed for presence and viability of eggs were not efficiently inactivated and eggs were still infectious (Figure 4b).

Conclusions

Our results showed that the WWTP combining a UASB reactor and submerged aerated biofilters was not able to remove high densities of bacteria, but was very efficient at removal of organic matter as well as producing low quantities of a stabilised sludge. Helminth eggs were also efficiently removed from the tertiary effluent and could be detected in the solid phase of treatment. A subsequent treatment using UV irradiation reduced thermotolerant coliforms, *E. coli*, salmonellae and coliphages to very low densities in the final effluent, rendering it safe to discard.

Acknowledgements

Brazilian Program of Basic Sanitation (PROSAB) and Fundo de Apoio à Ciência e Tecnologia do Município de Vitória (FACITEC) for financial support.

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