Simple wastewater treatment (UASB reactor, shallow polishing ponds, coarse rock filter) allowing compliance with different reuse criteria

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Abstract UASB reactors followed by polishing ponds comprise simple and economic wastewater treatment systems, capable of reaching very high removal efficiencies of pathogenic organisms, leading to the potential use of the effluent for unrestricted irrigation. However, for other types of reuse (urban and industrial), ponds are limited in the sense of producing effluents with high suspended solids (algae) concentrations. The work investigates a system with coarse rock filters for polishing the pond effluent. The overall performance of the system is analyzed, together with the potential for different types of reuse. The excellent results obtained (mean effluent concentrations: BOD: 27 mg/L; SS: 26 mg/L; *E. coli*: 450 MPN/100 mL) indicate the possibility of unrestricted use of the effluent for agriculture and restricted urban and industrial uses, according to WHO and USEPA.
Keywords Effluent use; polishing ponds; rock filters; UASB reactors

Introduction

Treated wastewater has been largely used in agriculture in several regions in the world, being supported by guidelines provided by the World Health Organization (WHO, 1989) for restricted and unrestricted irrigation. These guidelines establish limiting values of 1 helminth egg per litre (restricted and unrestricted irrigation) and 1000 thermotolerant coliforms per 100 mL (unrestricted irrigation). For other forms of reuse, different quality criteria are available, such as those from the United States Environmental Protection Agency (USEPA, 1992), summarized in Table 1. It should be observed that the North-American guidelines for irrigation are substantially more restrictive than those from the World Health Organization.

This research evaluates a sewage treatment system consisting of UASB reactor – shallow polishing ponds – coarse rock filters aiming at meeting several quality criteria for reuse. The system is simple, of low construction and operation costs, sustainable, unmechanized, with no power and chemical product consumption, and with relatively simple sludge handling.

Systems comprised of a UASB reactor followed by shallow polishing ponds in series have been investigated in different parts of Brazil, leading to good results in terms of organic matter removal and excellent results regarding coliform removal (Cavalcanti, 2003; Von Sperling *et al.*, 2003; Van Haandel and Lettinga, 2004; Von Sperling *et al.*, 2005). Polishing ponds in series have been proven to produce an effluent suitable for unrestricted irrigation. It is also worthy of mention that the pond system is the only one capable of removing the four categories of pathogenic organisms (bacteria, viruses, protozoan cysts and helminth eggs).

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Table 1 Limiting values suggested for different types of use of treated wastewater in the United States

Reuse of water	Type	Purposes of the treatment (limiting values)			
		BOD (mgL^{-1})	SS (mgL^{-1})	Turbidity (NTU)	Thermo coli ($MPN100\,mL^{-1}$)
Agricultural irrigation	Food crops	10		2	ND
	Non-food crops; food crops consumed after processing	30	30		200
Urban	Unrestricted	10		2	ND
	Restricted access irrigation	30	30		200
Recreational	Unrestricted	10		2	ND
	Restricted	30	30		200
Environmental enhancement		10		2	ND
Industrial reuse		30	30		200
Groundwater recharge		Site specific			
Potable reuse		Drinking water requirements			

ND = non detectable Incomplete table (there are other parameters and conditions not included)
Source: Levine and Asano (2004), adapting guidelines by USEPA (1992)

Methodology

The investigation was conducted at the UFMG-Copasa Experimental Treatment Plant, which is comprised of several treatment systems, and receives the actual wastewater from the city of Belo Horizonte, Brazil. This particular experiment involved the following units in series: one UASB reactor, three shallow polishing (maturation) ponds and one rock filter. The rock filter was inserted inside the last polishing pond, and was made of commercial crushed stone 3, with most of the diameters ranging from 3 to 8 cm. The main characteristics of the units are:

- UASB Reactor: Volume: 14.2 m^3; Height: 4.5 m; Diameter: 2.0 m; HDT: 7.5 h; Mean flow rate: 40 m^3/d
- Polishing Ponds 1 and 2: Length at bottom: 25.00 m; Width at bottom: 5.25 m; Depths: 0.80 m; HDT: 3.1 d (each pond); Mean flow rate: 40 m^3/d
- Polishing Pond 3: Length at bottom: 16.56 m; Width at the bottom: 5.25 m; Depth: 0.40 m; HDT: 4.2 d; Mean flow rate: 10 m^3/d
- Rock filter: Length at bottom: 8.44 m; Width at bottom: 5.25 m; Depth: 0.40 m; HDT: 2.0 d; Mean flow rate: 10 m^3/d

The total hydraulic detention time (volume/flow rate) in the system was of 12.7 days (UASB: 0.3 d; pond 1: 3.1 d; pond 2: 3.1 d; pond 3: 4.2 d; filter 1: 2.0 d).

The experiments discussed in this paper were conducted over 8 months (21/10/2004 to 30/06/2005) with a hydraulic loading rate (HLR) in the filters of 0.50 $m^3m^{-3}d^{-1}$. The hydraulic loading rate was established based on values reported by USEPA (2004), with HLR of 0.25 $m^3m^{-3}d^{-1}$ in California, Missouri, in 1975; Queiroz (2001), with a HLR of 0.04 $m^3m^{-3}d^{-1}$ in Brazil; USEPA (2004), in the State of Illinois, with a HLR of 0.80 $m^3m^{-3}d^{-1}$; Johnson and Mara (2005), in the United Kingdom, with a HLR of 0.15 $m^3m^{-3}d^{-1}$.

The system monitoring program consisted of a group of physical–chemical and microbiological analyses made once a week in the raw wastewater and in the effluent from the UASB reactor, the ponds and the filter. The raw wastewater was collected weekly by a 24-hour automatic composite sampler. The effluents from the units were grab samples.

Results and discussion

Tables 2 and 3 present the mean concentrations and mean removal efficiencies of BOD, SS and *E. coli* achieved in the system investigated. The concentrations of the nutrients

Table 2 Summary table of mean concentrations of BOD, SS and *E. coli*

Parameter	Mean effluent concentration					
	Raw wastewater	UASB	Pond 1	Pond 2	Pond 3	Filter 1
BOD[1]	235	46	38	36	40	27
SS[1]	187	60	84	72	108	26
E. coli[2]	2.03E + 08	4.24E + 07	2.29E + 05	3.34E + 04	1.00E + 03	4.50E + 02

[1]mgL^{-1}
[2]$MPN100\,mL^{-1}$
E. coli (geometric means)

Table 3 Summary table of mean removal efficiencies for BOD, SS and *E. coli*

Parameter	Mean removal efficiencies					
	UASB	Pond 1	Pond 2	Pond 3	Filter 1	Overall
Total BOD[1]	78	6	1	−10	37	88
SS[1]	68	−77	10	−73	73	85
E. coli[2]	0.71	2.21	0.84	1.52	0.44	5.68

[1]% of removal
[2]logarithmic units removed
Average efficiencies calculated based on the average influent and effluent concentrations of each unit

nitrogen and phosphorus are not analyzed here, since the desire to have higher or lower concentrations depends on the type of reuse (agricultural, industrial, urban, recreational). The tables show clearly the main characteristics already expected for each phase of the treatment: (a) UASB reactor: good BOD removal; (b) polishing ponds: excellent coliform removal, low BOD removal and SS production (algae); (c) rock filter: complementary BOD and, mainly, SS removal.

BOD

Although substantial, the reduction in the organic load brought about by the UASB reactor was complemented by the polishing ponds and, especially, the filter. Very good results were achieved for the BOD removal in the system as a whole. Table 4 and Figure 1 present the descriptive statistics of the concentrations in the system regarding BOD. The mean final effluent concentration was lower than $30\,mgL^{-1}$, a very low value, which allows several types of effluent use (see Table 1). It is worthy of mention that 90% of the BOD values were lower than $50\,mgL^{-1}$, which emphasizes the excellent performance of the system.

Suspended solids

Very good results were obtained for SS removal in the system as a whole (Table 5). As expected, the ponds were responsible for the increased SS concentrations due to algae

Table 4 Descriptive statistics of BOD concentrations in the system

Statistics	Raw wastewater	Effluent concentration				
		UASB	Pond 1	Pond 2	Pond 3	Filter
No. of data	21	20	23	24	24	21
Average (mgL^{-1})	235	46	38	36	40	27
Minimum (mgL^{-1})	92	14	12	11	6	5
Maximum (mgL^{-1})	479	108	105	105	115	106
Variation coeff.	0.47	0.60	0.56	0.59	0.70	0.88

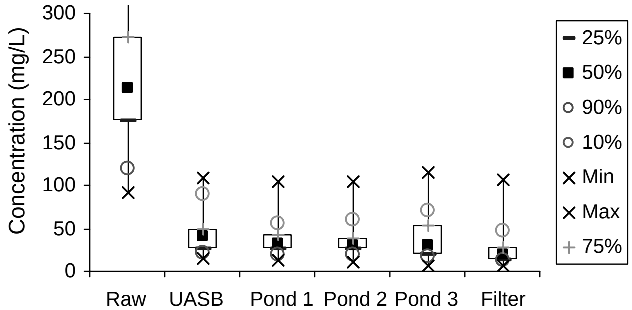

Figure 1 Box-plot of the concentrations of BOD in the system

production. However, the filter played its main role, leading to a significant solids removal (mean SS concentration reduced from 108 mgL^{-1} to 26 mgL^{-1}). The average effluent concentration was 26 mgL^{-1}, lower than the limiting value for several types of reuse (see Table 1). The maximum concentration observed in the effluent was 60 mgL^{-1}, evidencing the very good performance of the system.

The average SS removal efficiency in the filter amounted to 73%, while the overall average SS removal efficiency in the system was 85%. Figure 2 shows the variations of the SS concentrations throughout the system, while Figure 3 plots the cumulative distribution frequencies, highlighting the great contribution of the filters in terms of achieving different effluent SS concentrations.

E. coli

Regarding *E. coli* removal (Table 6 and Figure 4), excellent results have been achieved, considering the short total hydraulic detention time in such a natural system (12.7 days). The overall efficiency in the system was 5.68 logarithmic units removed, corresponding to a 99.9998% efficiency. As expected, the highest removal efficiencies occurred in the

Table 5 Descriptive statistics of SS concentration in the system

Statistics	Raw wastewater	Effluent concentration				
		UASB	Pond 1	Pond 2	Pond 3	Filter
No. of data	27	28	28	29	29	26
Average (mgL^{-1})	187	60	84	72	108	26
Minimum (mgL^{-1})	111	22	30	19	41	10
Maximum (mgL^{-1})	220	134	138	124	190	60
Variation coeff.	0.14	0.50	0.29	0.37	0.34	0.51

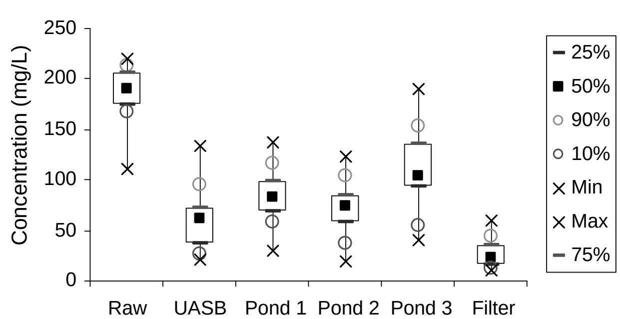

Figure 2 Box-plot of the SS concentrations in the system

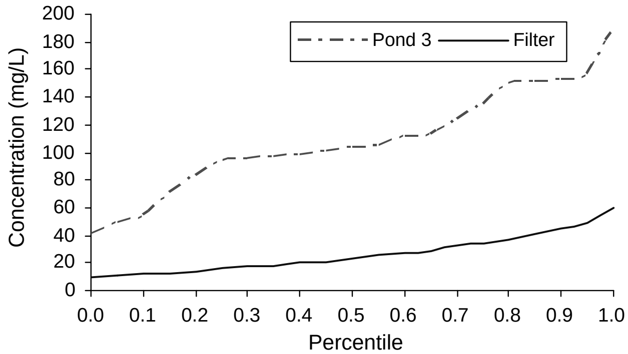

Figure 3 Cumulative frequency distribution of SS in the effluent from Pond 3 and filter

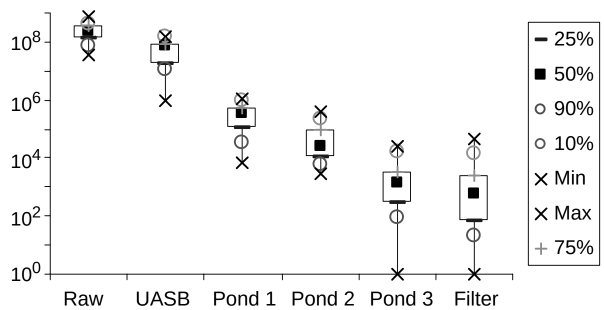

Figure 4 Box-plot of the *E. coli* concentrations in the system

three ponds in series, and the contribution of the filter was smaller (0.44 log units). The good results should be emphasized, taking into consideration the climate prevailing in the Brazilian southeast region (20° South). It is also worthy of mention that the ponds can have even better performances when operated in locations with more favorable climate, like in the northeast region of the country (Cavalcanti, 2003).

The final effluent presented a geometric mean lower than 1000 MPN100 mL^{-1}, thus meeting the World Health Organization (WHO, 1989) requirements for unrestricted irrigation. As expected, the most restrictive requirements provided for by the North-American guidelines regarding unrestricted irrigation (non-detectable concentrations) have not been met. It is possible to achieve the value of 200 MPN100 mL^{-1} for other types of effluent uses, provided that one or more ponds are added to the series. Although

Table 6 Descriptive statistics of *E. coli* concentrations in the system

Statistics	Raw wastewater	Effluent concentration				
		UASB	Pond 1	Pond 2	Pond 3	Filter
No. of data	25	26	27	27	27	25
Geometric mean (MPN 100 mL^{-1})	2.03×10^8	4.24×10^7	2.29×10^5	3.34×10^4	1.00×10^3	4.50×10^2
Minimum (MPN 100 mL^{-1})	3.80×10^7	1.00×10^6	7.40×10^3	2.80×10^3	1.00×10^0	1.00×10^0
Maximum (MPN 100 mL^{-1})	7.70×10^8	1.60×10^8	1.10×10^6	3.90×10^5	2.40×10^4	4.30×10^4
Variation coeff.	0.64	0.74	0.83	1.29	1.57	2.21

Table 7 Percentage of compliance with different limit values for use of treated wastewater, according to the World Health Organization (WHO, 1989) and USEPA (1992)

Parameter	Maximum value	Percentage of compliance (%)
BOD	10 mg/L	5
	30 mg/L	76
SS	30 mg/L	65
E. coli	Undetected	0
	200 MPN 100 mL^{-1}	36
	1000 MPN 100 mL^{-1}	56

Table 8 Interpretation of the compliance with the limiting values suggested for different types of use of treated wastewater, according to the World Health Organization (WHO, 1989) and USEPA (1992)

Guideline	Water reuse	Type	Possibility of compliance for different uses		
			BOD (mgL^{-1})	SS (mgL^{-1})	*E. coli* (MPN100 mL^{-1})
WHO (1989)	Agricultural irrigation	Unrestricted			√
		Restricted			√
	Agricultural irrigation	Food crops	No		No
		Non-food crops; food crops consumed after processing	√	√	Possible
USEPA (1992)	Urban	Unrestricted	No		No
		Restricted access areas	√	√	Possible
	Recreational	Unrestricted	No		No
		Restricted	√	√	Possible
	Environmental enhancement		No		No
	Industrial use		√	√	Possible

√: the average concentration meets the limiting value
No: unreachable limiting value; Blank cell: absence of limiting value in the guidelines; Guidelines: see Table 1; Possible: This limiting value can be achieved by adding one or more ponds to the series

not presented in this study, previous results show that the effluent is free from helminth eggs (Von Sperling *et al.*, 2005), thus meeting WHO criteria (1 eggL^{-1}) for restricted and unrestricted irrigation.

Compliance with different reuse criteria

Table 7 presents the percentage of the samples that comply with the limit concentrations established in the WHO and USEPA guidelines, while Table 8 presents a synthesis of the compliance with the different treated effluent use criteria (WHO and USEPA, as detailed in Table 1). The guidelines provided for by the World Health Organization (WHO, 1989) for restricted and unrestricted irrigation and by USEPA (1992) for certain restricted uses (urban, industrial and recreational) are fully met.

Conclusions

The system consisting of one UASB reactor, three shallow polishing ponds in series and one rock filter had an excellent performance, comparable to that from several more sophisticated wastewater treatment systems. The microbiological quality of the final effluent allows its use for unrestricted irrigation, according to the guidelines established by the World Health Organization. The quality of the final effluent in terms of BOD, SS and coliforms also allows its use in some restricted urban, recreational and industrial activities, as provided for by the North-American guidelines. Positive aspects are the simplicity of the system, absence of mechanization and power and absence of chemicals consumption, added to low construction and running costs. However, since the system is prevailingly natural, the area required is large (approximately $2-3\,m^2$/inhab).

Depending on the effluent use, the system can be even further simplified. If the effluent is to be used for agricultural irrigation, in order to accomplish the WHO (1989) guidelines, only the UASB reactor and the polishing ponds are necessary (no need to remove algae in the coarse filters).

Even though this paper discusses the operation of a period of eight months, the system continues in operation for almost two years, but with an intentionally higher hydraulic loading rate (double the rate of this research period – not covered in this paper). As a result of the higher loading, removal efficiencies decreased, but even so the general conclusions remain the same.

References

Cavalcanti, P.F.F. (2003). Integrated application of the UASB reactor and ponds for domestic sewage treatment in tropical regions. PhD thesis, Wageningen University, p. 141.

Johnson, M. and Mara, D.D. (2005). Aerated rock filters for enhanced nitrogen and faecal coliform removal from facultative waste stabilization pond effluents. *Wat. Sci. Tech.*, **51**(12), 99–102.

Levine, A.D. and Asano, T. (2004). Recovering sustainable water from wastewater. *Environmental Science and Technology*, American Chemical Society, June, pp. 201A-208A.

Queiroz, T.R. (2001). *Remoção de sólidos suspensos de efluentes de lagoas de estabilização por meio de processos naturais*. 229 p. Dissertação (Mestrado em Tecnologia Ambiental e Recursos Hídricos) Departamento de Engenharia Civil e Ambiental, Universidade de Brasília, Distrito Federal (in Portuguese).

USEPA (United States Environmental Protection Agency) (1992). *Guidelines for Water Reuse*, Washington.

USEPA (United States Environmental Protection Agency) (2004). *Wastewater Technology Fact Sheet. Rock Media Polishing Filter for Lagoons.* U.S. Environmental Protection Agency. Available from <http://www.epa.gov/OW-OWM.html/mtb/polfilla.pdf>. (Access: 18 Oct. 2004).

Van Haandel, A.C. and Lettinga, G. (2004). *Anaerobic Sewage Treatment: A Practical Guide for Regions with a Hot Climate*, John Wiley, Chichester, UK, p. 226.

Von Sperling, M., Jordão, E.P., Kato, M.T., Alem Sobrinho, P., Bastos, R.K.X. and Piveli, R. (2003). Capítulo 7: Lagoas de estabilização. In *Desinfecção de Efluentes Sanitários*, Gonçalves, R.F. (ed.), PROSAB/FINEP, Rio de Janeiro, pp. 277–336 (in Portuguese).

Von Sperling, M., Bastos, R.K.X. and Kato, M.T. (2005). Removal of *E. coli* and helminth eggs in UASB - polishing pond systems. *Water Science & Technology*, **51**(12), 91–97.

WHO (1989). *Health Guidelines for the Use of Wastewater in Agriculture and Aquaculture*, Geneva Technical Report Series 778. World Health Organization.