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Sterilization of swine wastewater treated by anaerobic reactors using UV photo-reactors

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ABSTRACT. The use of ultraviolet radiation is an established procedure with growing application forthe disinfection of contaminated wastewater. This study aimed to evaluate the efficiency of artificial UV radiation, as a post treatment of liquid from anaerobic reactors treating swine effluent. The UV reactors were employed to sterilize pathogenic microorganisms. To this end, two photo-reactors were constructed using PVC pipe with100 mm diameter and 1060 mm length, whose ends were sealed with PVC caps. The photo-reactors were designed to act on the liquid surface, as the lamp does not get into contact with the liquid. To increase the efficiency of UV radiation, photo-reactors were coated with aluminum foil. The lamp used in the reactors was germicidal fluorescent, with band wavelength of 230 nm, power of 30 Watts and manufactured by Techlux. In this research, the HRT with the highest removal efficiency was 0.063 days (90.6 minutes), even treating an effluent with veryhigh turbidity due to dissolved solids. It was concluded that the sterilization method using UV has proved to be an effective and appropriate process, among many other procedures.

Keywords: bacterial decay, water reuse, disinfection, advanced oxidation process.

Esterilização por fotólise de água residuária de suinocultura tratada em reatores anaeróbios, usando fotorreatores UV artificial

RESUMO. A radiação ultravioleta é uma forma estabelecida e de crescente aplicação como alternativa no processo de desinfecção das águas residuárias. O objetivo do presente trabalho é avaliar a eficiência da radiação UV artificial como processo de pós-tratamento de efluente líquido de suinocultura proveniente de reatores anaeróbios, visando a desinfecção e consequentemente a esterilização de patógenos. Para isso, utilizaram-se dois reatores fóticos construídos de tubos PVC brancos de 100 mm de diâmetro e 1.060 mm de comprimento. Suas extremidades foram lacradas com tampões de PVC. O reator fótico foi desenvolvido para atuar sobre o espelho líquido, sem que a lâmpada entrasse em contato com o efluente líquido. Para aumentar a eficiência da radiação UV, o reator foi revestido com papel alumínio. A lâmpada utilizada em cada um dos reatores era do tipo fluorescente germicida, com comprimento de onda da faixa de 230 nm, potência de 30 Watts e fabricada pela Techlux. Na presente pesquisa, o TDH adotado foi de 0,063 dias (90,6 min.) e apresentou elevada eficiência de remoção, mesmo tratando de efluentes com alto valor de turbidez e carga de sólidos dissolvidos. Concluiu-se que o processo de esterilização, utilizando reatores fóticos UV, demonstrou ser um dos mais adequados e eficientes entre vários processos pesquisados.

Palavras-chave: decaimento bacteriano, água para reuso, desinfecção, processos oxidativos avançados.

Introduction

The increasing population growth requires the development of agriculture, leading to a larger amount of agribusiness waste generated and consequently the production of industrial liquid effluents. At present, environmental agencies have increasingly demanded that these companies treat their effluent, in order to reach environmentally friendly parameter for discharge (CAMPOS et. al., 2010, 2013; SILVA et al., 2011a and b, 2013). Several alternatives for treating liquid effluents, including biological, chemical, oxidative formshave been developed. However, many industrial effluents contain pathogenic microbiological load, even after treated by biological processes forreuse purposes. Therefore, when the reuse of the wastewater is desirable, it is necessary a special treatment for removing pathogens (ALVES et al., 2012; CHERNICHARO et al., 2001; VON SPERLING, 2005).

Pathogenic organisms present in sewers are of great concern to humans, and include enteric bacteria, viruses, lactase positive enteric pathogens and intestinal parasites. Human sewage is often mixed with industrial and agro-industrial effluent sin order to raise the amount of nutrients and micronutrients to facilitate the biological treatment. Even in agro-industrial wastewaters, such as slaughterhouses, pig farms, among others, a wide range of pathogenic organisms isnormally present, and the transmission to humans may occur directly, when in contact with the contaminated effluent, or indirectly, when in contact with the medium or material contaminated (AGUIAR et al., 2002).

The use of ultraviolet radiation is an established procedure with growing application for the disinfection of water for supply and contaminated wastewater. However, in relation to sterilization of wastewaterbyultraviolet radiation, aiming its reuse in fertigation, few are the information in the literature, which demotivates the use of this process by the agro-industrial sector. The main mechanism of UV radiation action in sterilization is accomplished by means of interference withthe biosynthesis and cell reproduction (ABREU et al. 2013).

Microorganisms are inactivated as a result of the photochemical damage caused by UV radiation to their nucleic acids. Once damaged the deoxyribonucleic acid (DNA), which is responsible for the control of cellular functions, since the DNA gene controls the formation of ribonucleic acid (RNA), responsible for the instruction of specific enzymes and structural proteins, the reproduction process is compromised irreversibly. Genes are the basic units of the phosphoric acid, deoxyribose, purines (adenine and guanine) and pyrimidines (timinas and methylated). The combination of deoxyribose and phosphoric acid with one of the four bases, gives rise to a nucleotide. The base of each pair is set up through weak hydrogen bonds, leading the double chains of DNA to remain united. UV radiation is absorbed by these structures, breaking the bonds between the bases and making new connections between adjacent nucleotides, then forming double molecules or dimers of pyrimidines. Most dimers thymine-thymine is formed, and may also appear dimers of cytosine-cytosine and thymine-cytosine. The formation of a certain amount of dimers is enough to prevent the duplication of DNA, thus preventing the reproduction of the microorganism, since it impairs the protein synthesis.

The goal of this work was to evaluate the sterilization efficiency using artificial UV radiation as a post-treatment process.

Material and methods

The photo-reactors

Two photo-reactors were constructed using PVC pipe with 100 mm diameter and 1060 mm long. Its ends were sealed with PVC caps. For insertion of the lamp we made a superior cut in the pipe, rectangle-shaped with a length of 940 and 100 mm in width. Other PVC pipe with the same characteristics was also cut in the shape of a half circle, where was placed three steel docking latches for the fixation of UV lamp. The detailed lay-outis shown in Figure 1 (a and b). The photo-reactors were designed to act on the liquid surface, as the lamp does not get into contact with the liquid effluent. To increase the efficiency of UV radiation, the photo-reactors were coated with aluminum foil, increasing the exposure of the liquid and dissolved solids to radiation. The lamp used was germicidal fluorescent type, with band wavelength of 230 nm, power of 30 Watts and manufactured by Techlux, Figure 2 (a, b, c and d).

The wastewater used in the study was pretreated to remove organic matter, solids and nutrients in a system consisting of units of preliminary, primary and secondary treatment with two reactors in series described in Pereira et al. (2009, 2010a and b, 2011, 2013), Motteran et al. (2013a and b).

Monitoring physical, chemical and microbiological

The monitoring was carried out in six blocks, each block comprising 2 treatments, totaling 12 tests. In each treatment were collected three samples for analysis, each treatment was characterized by a concentration of total coliforms, turbidity and fecal coliforms (Table 1). Each test had different affluent outflow, thus varying the hydraulic retention time (HRT) and therefore the load of dissolved solids. Each photo-reactor had a net storage volume of 1.5 L, keeping a wastewater blade of 4 cm. The HRT and total dissolved solids load were calculated using the Equations 1 and 2:

$$TDH = \frac{V}{Q} \tag{1}$$

$$TDSL = Conc._{TDS} \, xQ \tag{2}$$

where:

TDSL: Total Dissolved Solids Load (g TDS h^{-1});

$Conc._{TDS}$: Total dissolved solids concentration (g L^{-1});

Q: Flow (L h^{-1});

V: Useful volume of the photo-reactor (L).

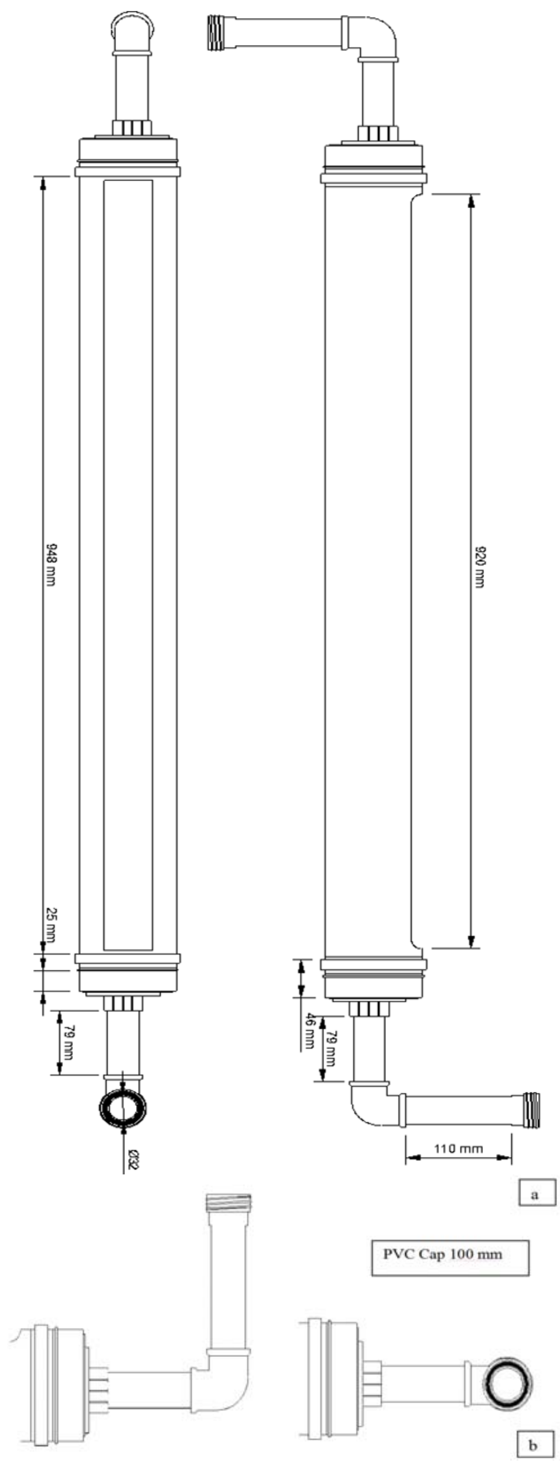

Figure 1. Schematic diagram of photo-reactors. (a) Side and top view. (b) Details of the PVC Cap (socket) on the endsof the photo-reactors.

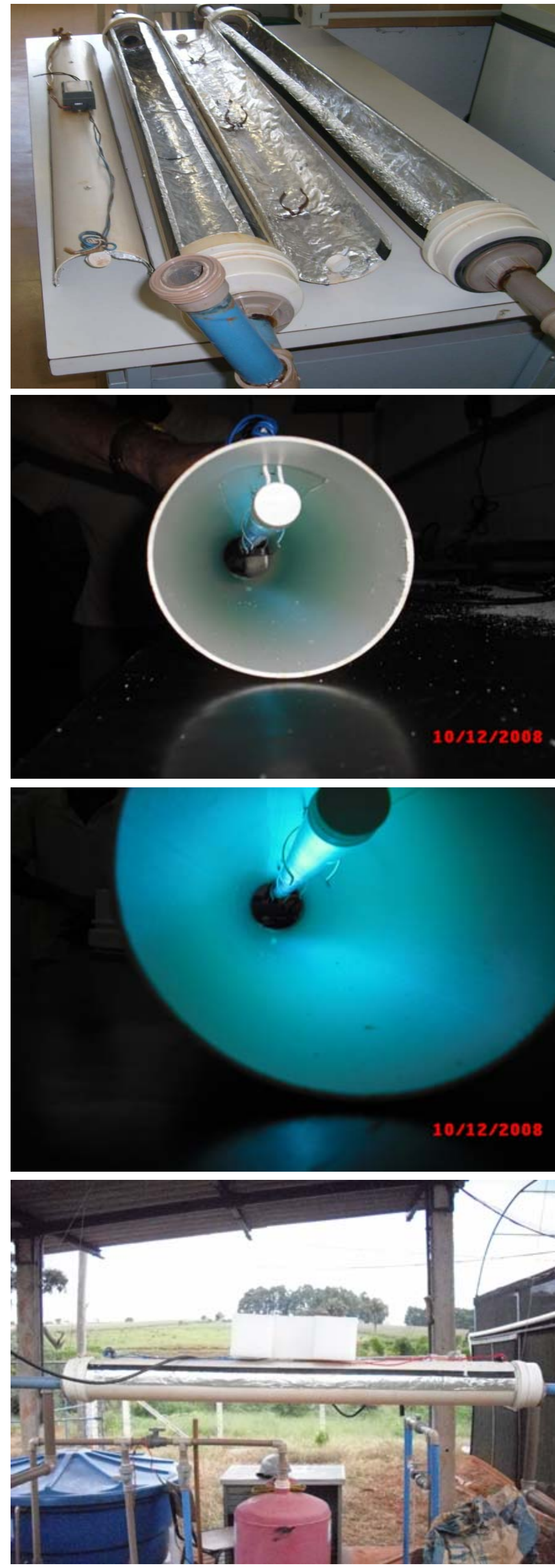

Figure 2. (a); (b); (c) and (d) Photo-reactors – photography.

Physicochemical evaluation was carried out by collecting, for the three repetitions, samples of 500 mL of the affluent and respective effluent of the reactor in sanitized PET bottles. Microbiological evaluation followed the same collection routine, but using 100 mL. The collected bottles were placed in polystyrene boxes and taken to the laboratory for physical, chemical and microbiological analysis (Table 1).

Table 1. Parameters analyzed and applied methodology.

Parameters	Methodology
pH	APHA, AWWA, WEF (2005)
Total Dissolved Solids (TDS), Fixed Dissolved Solids (FDS) and VolatileDissolved Solids (VDS)	APHA, AWWA, WEF (2005)
Turbidity	Turbidimeter
Total (TC) and Thermotolerant Coliforms (Term C.)	APHA, AWWA, WEF (2005) Multiple tubes methodology
Electrical Conductivity (E.C.)	Conductivimeter

Note: All analyses were made on a weekly basis.

Decay kineticsand removal efficiency of thermotolerant and total coliforms

With the data obtained in the 12 tests, the decay constants of total and thermotolerant coliforms were determined with the calculation described by Von Sperling (2005). The Equations 3, 4, 5, 6, and 7 used are listed below:

$$d = \left(\frac{L}{B} \right)^{-1} \quad (3)$$

$$\frac{N}{N_0} = \frac{4ae^{\frac{1}{2d}}}{(1+a)^2 xe^{\frac{a}{2d}} - (1-a)^2 xe^{\frac{-a}{2d}}} \quad (4)$$

$$A = \sqrt{1 + 4xK_b xtxd} \quad (5)$$

$$E = \left(\frac{C_A - C_E}{C_A} \right) x100 \quad (6)$$

$$ULR = -\log_{10} \frac{(100 - E)}{100} \quad (7)$$

where:

L: Length of the gutter exposed to UV radiation and subjected to radiation by reflection (m);

B: Width of the wet section exposed to UV radiation and subjected to radiation by reflection (m);

d: dispersion coefficient;

K_b: Decay constant of total or thermotolerant coliforms (day^{-1});

N: Effluent concentration of total or thermotolerant coliforms (MPN 100 mL^{-1});

N_0: Affluent concentration of total or thermotolerant coliforms (MPN 100 mL^{-1});

MPN: Most probable number;

t: Contact time of the effluent with UV radiation, for this we used the values of HRT (d), which defined the 12 tests.

E: Efficiency in percentage (%);

LUR: Logarithmic units removed (dimensionless).

Results and discussion

During the UV sterilization process, the main physical-chemical and microbiological parameters capable of interfering with the sterilization process were:

The concentration of total suspended solids (TSS) that serve as a shield against UV rays protecting microorganisms against the exposure to radiation. This parameter can be estimated by turbidity.

The color; as the greater the color unit the lower the refractive index of the medium, and therefore the lower the penetration of UV rays intothe liquid. The color is directly influenced by the concentration of dissolved solids, which is an extremely important parameter to be determined, able to replace colorimetric analysis.

The initial concentration of total and thermotolerant coliforms in the liquid.

The pH of the liquid, since the conditions of acidity and alkalinity also interfere with the UV sterilization process.

Table 1 shows the initial conditions of the wastewater treated by the photo-reactor. The values of pH showed that sterilization efficiencies were only due to the radiation process, since the liquid remained buffered before and after the process in all tests (Tables 2 and 3).

As the covariance values (C.V.) of pH data are low, there was no sudden change in pH, which could have resulted in reduction of coliforms. Also, it was possible to see that the tests were conducted with high concentrations of coliforms, high values of total dissolved solids (TDS) and turbidity when compared to other studies regarding the removal of pathogenic organisms (BOTTO et al., 2009; CARDOSO et al., 2003; LAPOLLI et al. 2005; LUCA et al., 2002; PATERNIANI; SILVA, 2005).

Analyzing the data presented in Table 3 with the data presented in Table 2, comparing the tests with the same effluent turbidity, TDSLR (E1 x E2), (E3 x E4, E5 x E6, E7 x E8, E9 x E10, E11 x E12), we observed that the increase in HRT leads toenhanced efficiency of removal of total and thermotolerant coliforms. The tests E7, E9, and E10 showed a high removal in logarithmic scale.

Table 2. Characteristic of each test in relation to the HRT, solid load, affluent bacterial concentration and turbidity.

Test	Descriptive Statistics	Operational Parameters			Physico-chemical and microbiological Parameters			
		HRT	Q	TDSLR	Turbidity	pH	TC	Therm.C
E1	Md.	0.0082	182.62	386.13	1037.0	6.3	1.00E+08	1.00E+08
	Min.	0.0082	182.62	362.80	1032.0	3.8	1.00E+08	1.00E+08
	Max.	0.0082	182.62	409.47	1042.0	7.6	1.00E+08	1.00E+08
	C.V.	0.0000	0.00	0.09	0.0	0.3	0.00E+00	0.00E+00
	S.D.	0.0000	0.00	33.00	7.1	2.1	0.00E+00	0.00E+00
E2	Md.	0.0104	143.96	304.40	1503.3	6.3	6.67E+07	1.00E+08
	Min.	0.0104	143.96	286.00	1032.0	3.8	5.56E+03	1.00E+08
	Max.	0.0104	143.96	322.79	2436.0	7.6	1.00E+08	1.00E+08
	C.V.	0.0000	0.00	0.09	0.5	0.3	8.66E-01	0.00E+00
	S.D.	0.0000	0.00	26.01	807.7	2.1	5.77E+07	0.00E+00
E3	Md.	0.0243	61.86	128.35	1110.0	7.6	5.73E+11	5.73E+11
	Min.	0.0243	61.86	118.76	1110.0	7.5	4.50E+10	4.50E+10
	Max.	0.0243	61.86	137.94	1110.0	7.6	1.10E+12	1.10E+12
	C.V.	0.0000	0.00	0.11	0.0	0.0	1.30E+00	1.30E+00
	S.D.	0.0000	0.00	13.56	0.0	0.1	7.46E+11	7.46E+11
E4	Md.	0.0468	32.07	66.55	1110.0	7.6	5.73E+11	5.73E+11
	Min.	0.0468	32.07	61.58	1110.0	7.5	4.50E+10	4.50E+10
	Max.	0.0468	32.07	71.52	1110.0	7.6	1.10E+12	1.10E+12
	C.V.	0.0000	0.00	0.11	0.0	0.0	1.30E+00	1.30E+00
	S.D.	0.0000	0.00	7.03	0.0	0.1	7.46E+11	7.46E+11
E5	Md.	0.0444	33.78	61.28	1017.5	7.4	2.63E+09	2.63E+09
	Min.	0.0444	33.78	61.25	1000.0	7.4	7.50E+08	7.50E+08
	Max.	0.0444	33.78	61.32	1035.0	7.5	4.50E+09	4.50E+09
	C.V.	0.0000	0.00	0.00	0.0	0.0	1.01E+00	1.01E+00
	S.D.	0.0000	0.00	0.05	24.7	0.0	2.65E+09	2.65E+09
E6	Md.	0.2442	6.14	11.15	1017.5	7.4	2.63E+09	2.63E+09
	Min.	0.2442	6.14	11.14	1000.0	7.4	7.50E+08	7.50E+08
	Max.	0.2442	6.14	11.15	1035.0	7.5	4.50E+09	4.50E+09
	C.V.	0.0000	0.00	0.00	0.0	0.0	1.01E+00	1.01E+00
	S.D.	0.0000	0.00	0.01	24.7	0.0	2.65E+09	2.65E+09
E7	Md.	0.2223	6.75	13.01	1030.0	7.5	3.60E+08	3.60E+08
	Min.	0.2223	6.75	12.96	1027.0	7.5	2.70E+08	2.70E+08
	Max.	0.2223	6.75	13.07	1033.0	7.5	4.50E+08	4.50E+08
	C.V.	0.0000	0.00	0.01	0.0	0.0	3.54E-01	3.54E-01
	S.D.	0.0000	0.00	0.08	4.2	0.0	1.27E+08	1.27E+08
E8	Md.	0.2444	6.14	11.83	1030.0	7.5	3.60E+08	3.60E+08
	Min.	0.2444	6.14	11.78	1027.0	7.5	2.70E+08	2.70E+08
	Max.	0.2444	6.14	11.88	1033.0	7.5	4.50E+08	4.50E+08
	C.V.	0.0000	0.00	0.01	0.0	0.0	3.54E-01	3.54E-01
	S.D.	0.0000	0.00	0.07	4.2	0.0	1.27E+08	1.27E+08
E9	Md.	0.2863	5.24	10.79	1073.0	7.5	1.25E+14	1.25E+14
	Min.	0.2863	5.24	10.53	1070.0	7.5	1.10E+14	1.10E+14
	Max.	0.2863	5.24	11.05	1076.0	7.5	1.40E+14	1.40E+14
	C.V.	0.0000	0.00	0.03	0.0	0.0	1.70E-01	1.70E-01
	S.D.	0.0000	0.00	0.37	4.2	0.0	2.12E+13	2.12E+13
E10	Md.	1.5151	0.99	2.05	1073.0	7.5	1.25E+14	1.25E+14
	Min.	1.5151	0.99	2.00	1070.0	7.5	1.10E+14	1.10E+14
	Max.	1.5151	0.99	2.10	1076.0	7.5	1.40E+14	1.40E+14
	C.V.	0.0000	0.00	0.03	0.0	0.0	1.70E-01	1.70E-01
	S.D.	0.0000	0.00	0.07	4.2	0.0	2.12E+13	2.12E+13
E11	Md.	0.0588	25.49	52.06	911.0	7.7	2.80E+09	2.80E+09
	Min.	0.0588	25.49	41.80	910.0	7.7	1.10E+09	1.10E+09
	Max.	0.0588	25.49	62.32	912.0	7.7	4.50E+09	4.50E+09
	C.V.	0.0000	0.00	0.28	0.0	0.0	8.59E-01	8.59E-01
	S.D.	0.0000	0.00	14.51	1.4	0.0	2.40E+09	2.40E+09
E12	Md.	0.2049	7.32	14.95	911.0	7.7	2.80E+09	2.80E+09
	Min.	0.2049	7.32	12.00	910.0	7.7	1.10E+09	1.10E+09
	Max.	0.2049	7.32	17.89	912.0	7.7	4.50E+09	4.50E+09
	C.V.	0.0000	0.00	0.28	0.0	0.0	8.59E-01	8.59E-01
	S.D.	0.0000	0.00	4.17	1.4	0.0	2.40E+09	2.40E+09

HRT (h): Hydraulic Retention Time; Q ($L\ h^{-1}$): flow; TDSLR (g TDS h^{-1}): Total Dissolved Solids Load; Turbidity (NTU); T. C. (MPN 100 mL^{-1}): Concentration of Total Coliforms; Term. C. (MPN 100 mL^{-1}): Concentration of Thermotolerant Coliforms; Min: minimum value; Max.: maximum value; Md.: Average; S.D.: Standard Deviation. C.V.: Coefficient of Variation (dimensionless- calculated by the ratio= S.D./Md); MPN: Most Probable Number.

Table 3. Characteristics of the effluent of photo-reactors in each test in relation to concentration of T.C. and Thermotolerant C. and respective bacterial decay constant (Kb).

		Coliform concentration		Removal of TC		Removal of Thermotolerant C.		Kb	
Test	Descriptive Statistics	Total	Term.	Ef. (%)	Ef. log	Ef. (%)	Ef. log	Kb total	Kb fecal
E1	Md	4.40E+06	4.40E+06	95.600	1.625	95.600	1.625	1.48E+04	1.48E+04
	Min.	1.10E+06	1.10E+06	89.000	0.959	89.000	0.959	7.67E+03	7.67E+03
	Max.	1.10E+07	1.10E+07	98.900	1.959	98.900	1.959	1.83E+04	1.83E+04

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		Coliform concentration		Removal of TC		Removal of Thermotolerant C.		Kb	
Test	Descriptive Statistics	Total	Term.	Ef. (%)	Ef. log	Ef. (%)	Ef. log	Kb total	Kb fecal
	CV	1.30E+00	1.30E+00	0.060	0.355	0.060	0.355	4.16E-01	4.16E-01
	Med.	1.10E+06	1.10E+06	98.900	1.959	98.900	1.959	1.83E+04	1.83E+04
	M.G.	2.37E+06	2.37E+06	95.483	1.544	95.483	1.544	1.37E+04	1.37E+04
	S.D.	5.72E+06	5.72E+06	5.716	0.577	5.716	0.577	6.13E+03	6.13E+03
	Md	5.32E+05	5.32E+05	99.468	2.551	99.468	2.551	2.08E+04	2.08E+04
	Min.	4.50E+04	4.50E+04	98.900	1.959	98.900	1.959	1.44E+04	1.44E+04
	Max.	1.10E+06	1.10E+06	99.955	3.347	99.955	3.347	2.96E+04	2.96E+04
E2	CV	1.00E+00	1.00E+00	0.005	0.281	0.005	0.281	3.80E-01	3.80E-01
	Med.	4.50E+05	4.50E+05	99.550	2.347	99.550	2.347	1.82E+04	1.82E+04
	M.G.	2.81E+05	2.81E+05	99.467	2.487	99.467	2.487	1.98E+04	1.98E+04
	S.D.	5.32E+05	5.32E+05	0.532	0.716	0.532	0.716	7.90E+03	7.90E+03
	Md	4.60E+10	6.21E+08	91.965	1.313	99.891	3.443	3.85E+03	1.36E+04
	Min.	1.40E+10	1.40E+07	80.786	0.716	99.755	2.612	1.86E+03	9.04E+03
	Max.	1.10E+11	1.40E+09	97.555	1.612	99.998	4.612	4.85E+03	2.02E+04
E3	CV	1.20E+00	1.14E+00	0.105	0.394	0.001	0.303	4.47E-01	4.33E-01
	Med.	1.40E+10	4.50E+08	97.555	1.612	99.921	3.105	4.85E+03	1.15E+04
	M.G.	2.78E+10	2.07E+08	91.610	1.230	99.891	3.344	3.52E+03	1.28E+04
	S.D.	5.54E+10	7.09E+08	9.681	0.517	0.124	1.042	1.72E+03	5.88E+03
	Md	1.40E+08	1.40E+07	99.976	3.612	99.998	4.612	7.35E+03	1.05E+04
	Min.	1.40E+08	1.40E+07	99.976	3.612	99.998	4.612	7.35E+03	1.05E+04
	Max.	1.40E+08	1.40E+07	99.976	3.612	99.998	4.612	7.35E+03	1.05E+04
E4	CV	0.00E+00	0.00E+00	0.000	0.000	0.000	0.000	0.00E+00	0.00E+00
	Med.	1.40E+08	1.40E+07	99.976	3.612	99.998	4.612	7.35E+03	1.05E+04
	M.G.	1.40E+08	1.40E+07	99.976	3.612	99.998	4.612	7.35E+03	1.05E+04
	S.D.	0.00E+00	0.00E+00	0.000	0.000	0.000	0.000	0.00E+00	0.00E+00
	Md	5.56E+07	5.73E+07	97.884	2.378	97.819	2.072	4.61E+03	3.76E+03
	Min.	1.10E+06	4.50E+06	95.810	1.378	95.810	1.378	2.18E+03	2.18E+03
	Max.	1.10E+08	1.10E+08	99.958	3.378	99.829	2.766	7.04E+03	5.34E+03
E5	CV	1.39E+00	1.30E+00	0.030	0.595	0.029	0.474	7.45E-01	5.93E-01
	Med.	5.56E+07	5.73E+07	97.884	2.378	97.819	2.072	4.61E+03	3.76E+03
	M.G.	1.10E+07	2.22E+07	97.862	2.157	97.798	1.952	3.92E+03	3.41E+03
	S.D.	7.70E+07	7.46E+07	2.933	1.414	2.842	0.982	3.43E+03	2.23E+03
	Md	5.73E+06	5.50E+04	99.782	3.072	99.998	4.378	1.14E+03	2.51E+03
	Min.	4.50E+05	0.00E+00	99.581	2.378	99.996	4.378	7.92E+02	1.86E+03
	Max.	1.10E+07	1.10E+05	99.983	3.766	100.000	4.378	1.49E+03	3.15E+03
E6	CV	1.30E+00	1.41E+00	0.003	0.320	0.000	0.000	4.34E-01	3.63E-01
	Med.	5.73E+06	5.50E+04	99.782	3.072	99.998	4.378	1.14E+03	2.51E+03
	M.G.	2.22E+06	-	99.782	2.992	99.998	4.378	1.09E+03	2.42E+03
	S.D.	7.46E+06	7.78E+04	0.284	0.982	0.003	0.00	4.97E+02	9.11E+02
	Md	1.10E+06	2.27E+03	99.694	2.515	99.999	5.991	9.38E+02	3.06E+03
	Min.	1.10E+06	3.00E+01	99.694	2.515	99.999	4.903	9.38E+02	2.44E+03
	Max.	1.10E+06	4.50E+03	99.694	2.515	100.000	7.079	9.38E+02	3.68E+03
E7	CV	0.00E+00	1.40E+00	0.000	0.000	0.000	0.257	0.00E+00	2.87E-01
	Med.	1.10E+06	2.27E+03	99.694	2.515	99.999	5.991	9.38E+02	3.06E+03
	M.G.	1.10E+06	3.67E+02	99.694	2.515	99.999	5.892	9.38E+02	2.99E+03
	S.D.	0.00E+00	3.16E+03	0.000	0.000	0.001	1.539	0.00E+00	8.78E+02
	Md	6.83E+05	9.33E+05	99.810	2.856	99.741	3.734	1.02E+03	1.85E+03
	Min.	2.00E+05	1.50E+02	99.611	2.410	99.611	2.410	8.06E+02	8.06E+02
	Max.	1.40E+06	1.40E+06	99.944	3.255	100.000	6.380	1.21E+03	3.94E+03
E8	CV	9.27E-01	8.66E-01	0.002	0.149	0.002	0.614	2.01E-01	9.78E-01
	Med.	4.50E+05	1.40E+06	99.875	2.903	99.611	2.410	1.04E+03	8.06E+02
	M.G.	5.01E+05	6.65E+04	99.810	2.835	99.741	3.334	1.00E+03	1.37E+03
	S.D.	6.33E+05	8.08E+05	0.176	0.424	0.225	2.292	2.04E+02	1.81E+03
	Md	5.53E+06	7.37E+05	100.000	7.518	100.000	8.722	2.48E+03	3.19E+03
	Min.	1.10E+06	1.10E+04	100.000	7.056	100.000	8.056	7.28E+02	2.86E+03
	Max.	1.10E+07	1.10E+06	100.000	8.056	100.000	10.056	3.85E+03	3.85E+03
E9	CV	9.09E-01	8.53E-01	0.000	0.067	0.000	0.132	6.44E-01	1.80E-01
	Med.	4.50E+06	1.10E+06	100.000	7.444	100.000	8.056	2.86E+03	2.86E+03
	M.G.	3.79E+06	2.37E+05	100.000	7.507	100.000	8.674	2.00E+03	3.15E+03
	S.D.	5.03E+06	6.29E+05	0.000	0.504	0.000	1.155	1.60E+03	5.75E+02
	Md	2.23E+06	5.17E+05	100.000	7.852	100.000	9.373	5.98E+02	5.98E+02
	Min.	1.10E+06	3.00E+02	100.000	7.444	100.000	8.056	5.17E+02	5.17E+02
	Max.	4.50E+06	1.10E+06	100.000	8.056	100.000	11.620	6.38E+02	6.38E+02
E10	CV	8.79E-01	1.07E+00	0.000	0.045	0.000	0.209	1.16E-01	1.16E-01
	Med.	1.10E+06	4.50E+05	100.000	8.056	100.000	8.444	6.38E+02	6.38E+02
	M.G.	1.76E+06	5.30E+04	100.000	7.846	100.000	9.246	5.95E+02	5.95E+02
	S.D.	1.96E+06	5.53E+05	0.000	0.353	0.000	1.955	6.96E+01	6.96E+01
	Md	2.35E+04	0.00E+00	99.999	5.470	100.000	0	1.14E+04	1.36E+04
	Min.	2.00E+03	0.00E+00	99.998	4.794	100.000	0.000	8.87E+03	1.32E+04
	Max.	4.50E+04	0.00E+00	100.000	6.146	100.000	0.000	1.39E+04	1.39E+04
E11	CV	1.29E+00	-	0.000	0.175	0.000	-	3.12E-01	3.40E-02
	Med.	2.35E+04	0.00E+00	99.999	5.470	100.000	-	1.14E+04	1.36E+04
	M.G.	9.49E+03	-	99.999	5.428	100.000	-	1.11E+04	1.36E+04
	S.D.	3.04E+04	0.00E+00	0.001	0.956	0.000	-	3.56E+03	4.62E+02

Continue...

...continuation.

Test	Descriptive Statistics	Coliform concentration Total	Coliform concentration Term.	Removal of TC Ef. (%)	Removal of TC Ef. log	Removal of Thermotolerant C. Ef. (%)	Removal of Thermotolerant C. Ef. log	Kb total	Kb fecal
E12	Md	3.88E+04	1.00E+02	99.999	5.449	100.000	6.970	3.26E+03	4.08E+03
	Min.	2.00E+03	0.00E+00	99.996	4.406	100.000	6.970	2.24E+03	3.74E+03
	Max.	1.10E+05	3.00E+02	100.000	6.146	100.000	6.970	3.81E+03	4.68E+03
	CV	1.59E+00	1.73E+00	0.000	0.169	0.000	-	2.72E-01	1.29E-01
	Med.	4.50E+03	0.00E+00	100.000	5.794	100.000	6.970	3.74E+03	3.81E+03
	M.G.	9.97E+03	-	99.999	5.393	100.000	6.970	3.17E+03	4.06E+03
	S.D.	6.16E+04	1.73E+02	0.002	0.920	0.000	-	8.89E+02	5.25E+02

Ef (%): Removal Efficiency in Percentages; Ef Log.: Removal Efficiency in Logarithm; Kb total (day^{-1}): Constant of Total Coliforms Decay; Kb Term. (day^{-1}): Constant of Thermotolerant Coliform Decay; MG.: Geometric Average; Min: minimum value; Max.: maximum value; Med.: Median; S.D. Standard Deviation. Md: Average; C.V.: Coefficient of Variation (dimensionless- calculated by the ratio= S.D./Md); MPN: Most Probable Number.

The test conditions of E10 with relatively high turbidity compared to the other tests, with three repetitions, showed a high efficiency in logarithmic scale (11.62).

A value as high as that one was not found in the literature (LAPOLLI et al. 2005; DUDA; OLIVEIRA, 2009; RODRIGUES et al. 2009).The decay constants of total and thermotolerant coliforms were high due to the low HRT of the photo-reactors. The UV radiation in the photo-reactorshas high intensity and is constant because of the use of the germicidal lamp instead of solar radiation, as normally observed in maturation ponds, thus, even when subjected to short HRT, it is possible to reach high efficiencies (Tables 2 and 3).

Lapolli et al. (2005) evaluated five concentrations of chlorine dioxide (ClO_2) in the disinfection of sanitary waste, with initial concentration of fecal coliforms of 2.6 x 10^4 MPN 100 mL^{-1}, and reported total removal of fecal coliforms at levels of ClO_2 of 2.0, 2.5 and 3.0 mg L^{-1} with contact times of 10, 15 and 20 minutes, respectively. However, levels of 2.5 and 3.0 mg L^{-1} ClO_2 disinfected the sewage, with pH values below the lower limit set forth by the Brazilian norm NBR 13969 (ABNT, 1997), and a residual concentration of ClO_2 above the established by the EPA (1994) USA.

Rodrigues et al. (2009) used a maturation pond as polishing for removal of coliformsfrom pig farming wastewater treated in UASB reactor, and reached a reduction of 1.33 in logarithmic units of thermotolerant coliforms, and an effluent with average concentration of 1.1 x 10^3 MPN 100 mL^{-1} of thermotolerant coliforms. Bacterial decay coefficients for the same polishing pond cited above, determined at a temperature of 20°C, for the mixing of hydraulic and dispersed flow, were 0.98 and 0.23 day^{-1}, respectively.

Moreover, Duda and Oliveira (2009) examined the polishing of effluent from anaerobic reactors treating pig farming wastewaterin sequential batch reactors, and evaluated a system of polishing ponds for removal of coliforms, applying 3 tests with varying HRT. In the test 1, the treated effluent had concentrations of coliforms about 2.5 x 10^7 MPN 100mL^{-1} and thermotolerant coliforms about 1.4 x 10^7 MPN 100 mL^{-1}, and was subjected to HRT of 33.2h, resulting in an effluent with coliform concentration of 8 x 10^4 MPN 100 mL^{-1} and 8 x 10^3 MPN 100 mL^{-1} of thermotolerant coliforms. In the test 2, the treated effluent had coliforms concentration of 7.5 x 10^8 MPN 100 mL^{-1} and thermo coliforms about 4 x 10^7 MPN 100 mL^{-1}, and was subjected to HRT of 25h, resulting in an effluent with coliform concentration of 9 x 10^4 MPN 100 mL^{-1} and thermotolerant coliforms of 9 x 10^4 MPN 100 mL^{-1}. In the test 3, the concentration of total coliforms in the treated effluent was 1.2 x 10^9 MPN 100 mL^{-1} and of thermotolerant coliforms was 1.6 x 10^8 MPN 100 mL^{-1} with a HRT of 16.6h, resulting in an effluent with coliforms concentration of 1.1 x 10^5 MPN 100 mL^{-1}, and thermotolerant coliforms of 2.5 x 10^4 MPN 100 mL^{-1}.

Considering the work cited above, it is clear that the authors used very high HRT values when compared to those adopted herein, and found removal efficiencies lower than those in the present work. In addition, other specific characteristics of the studies cited impede the comparison to the photo-reactors used in this survey, since polishing ponds (maturation) require large areas, unlike photo-reactors, which require insignificant areas. Another problem of polishing ponds is that they depend on sunlight for sterilization, compromising the efficiency in cloudy days or in areas with little radiation.

The application of chlorine for disinfection demand less contact time or HRT than the polishing pond, nevertheless, it is unfeasible for discharges, since it forms carcinogenic compounds, such as trihalomethanes and other organochlorine compounds, resulting from the reaction of chlorine with oxidized organic matter, in addition, chlorine-rich water can be detrimental for fertigation, due to the toxicity for most cultivars.As the concentration of TDS is an important parameter for the performance of the ultraviolet sterilization process, but at the same time it is a time-consuming analysis according to its methodology, we generated models to estimate the amount of TDS according to parameters such as turbidity and Electrical Condutivity of effluent (E.C.) The correlations are described below:

EC x TDS: TDS = 1547.9 x $CE^{0}.09$ $R^2 = 0.70$

Turbidity x TDS: TDS = 6.6204 x $Turbidity^{0}.83$ $R^2 = 0.75$

Conclusion

The sterilization process using UV photo-reactors has proved to be one of the most effective and appropriate procedure among several processes investigated. In this research, the HRT adopted was 0.063 days (90.6 minutes), being more viable than other methods of sterilization, with high removal efficiency, even treating effluent with high turbidity and dissolved solids values.

In terms of cost-benefit, the expenses with power should not be regarded as a disadvantage due to the low cost of electricity in rural areas, and also the requirement for smaller areas, since the removal efficiency is high, even when the hydraulic retention time is short, thus allowing low power values for high volume of treated effluent.

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