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ANAEROBIC EFFLUENT POST-TREATMENT APPLYING PHOTOLYTIC REACTOR PRIOR TO AGRICULTURAL USE IN BRAZILIAN'S SEMIARID REGION

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Abstract: This work applied a Compact System consisting of a Reactor Up flow Sludge Blanket (UASB) in conjunction with s Submerged Anaerobic Filter containing polyurethane cubes as support media, followed by a Solar Photolytic Reactor. The compact anaerobic system produced a clarified effluent with low concentration of organic matter, especially dissolved (20 mg .VSS/L), and free of helminthes eggs. These low concentrations of suspended solids facilitated photolytic disinfection process producing a good quality final effluent, of which 90% of the samples were thoroughly disinfected, while the other fraction showed concentration of Thermotolerant Coliform (TTC) at or below 100 CFU/100 mL and high concentrations of nutrients (48 mg . NH_4^+-N/L and 6,4mg PO_4^{-3}-P/L) enabling the use of irrigation for productive purposes. Another advantages of the compact anaerobic treatment consisted of low sludge production, and relatively simple operation without energy consumption. These advantages results in a significant reduction in operational costs of sewage treatment, and, indeed, an outlet for developing countries in tropical climate.

Keywords: Anaerobic system; post-treatment; photolytic reactor; removal of pathogenic organisms.

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INTRODUCTION

Access to sanitation can be understood as an indicator of a society development state. The universalisation and improvement in quality of sanitation services can be considered as one of the biggest challenges of the country, requiring an investment of 178 billion dollars over the next 20 years (UNDP, 2004).

Treating sewage properly, with secondary treatment followed by a tertiary one, like filtration and disinfection for production of sanitary quality effluent required by the World Health Organization can be too expensive and difficult to implement, especially in developing countries. From a practical point of view searching new technologies or adapt existing ones is a desirable goal in order to deal more economical and environmentally with the large amount of sewage generated by urban and suburban populations.

The application of anaerobic treatment systems is of great importance, as they allow the removal of organic matter without the need for energy consumption required in aerobic processes. Other advantages include: low production of solid methane formation (which can be recovered) and disposing of equipment for aeration.

Among the major technological advances in the application of anaerobic digestion processes in wastewater treatment is the development of the UASB, especially for application in tropical and subtropical countries, where the temperature stays above 20 °C. Their efficiency is related to the flow direction and configuration (presence of three phase separator), which allows longer cell retention, while providing an adequate stirring and mixing between the affluent and the sludge blanket Foresti *et al.*, 2006).

The UASB reactor consists of a low cost alternative in the treatment of domestic sewage, providing a removal of about 70% of BOD_5 and low hydraulic retention time (HRT) from 5 to 8 hours (Além Sobrinho; Kato, 1999). However, the disposal of effluents into water bodies requires post-treatment to reduce or eliminate pathogens and reduce the concentration of nutrients like nitrogen and phosphorus.

When the destination is the reuse of wastewater in agriculture, necessarily, there is demand for removal or inactivation of pathogenic organisms like viruses, bacteria, protozoa and helminthes, which create serious public health problems affecting workers in plantations as well as consumers of these cultures (Sousa *et al.*, 2009).

The microorganisms present in domestic wastewater are usually vulnerable to heat and ultraviolet radiation. Once the sun is a free available source of heat and radiation it can be used as a source of UV disinfection processes. So, one can use photolysis process via UV for effluent disinfection, especially in semiarid region of Northeast Brazil, where the sunshine lasts an average of 2,800 h/year (Sousa *et al.*, 2005).

In this context, this study propose was to apply an anaerobic treatment of domestic sewage using system composed by a compact anaerobic UASB combined with anaerobic filter and effluent post-treatment in Solar Photolytic Reactor. It is understood as a low-cost technology able to produce effluent of good sanitary quality, low organic load and considerable concentration of nutrients.

MATERIAL AND METHODS

The experiment took place at the station of Biological Treatment of Sewage (EXTRABES) located in an area belonging both to the Company of Water and Sewers of Paraiba state (CAGEPA) and the State University of Paraiba in Campina Grande, Paraiba State, with altitude of 550 m.

The municipal wastewater used during the experiment was captured by a submersible pump installed in an inspection well from the CAGEPA's sewer Interceptor Pipe. The sewage fed by gravity, through plastic hoses of 20 mm in diameter, a box of 100 liters, where there was peristaltic metering pump with preset flow feeding system.

The experimental system of wastewater treatment illustrated in **Fig. 1** was composed of two units. The

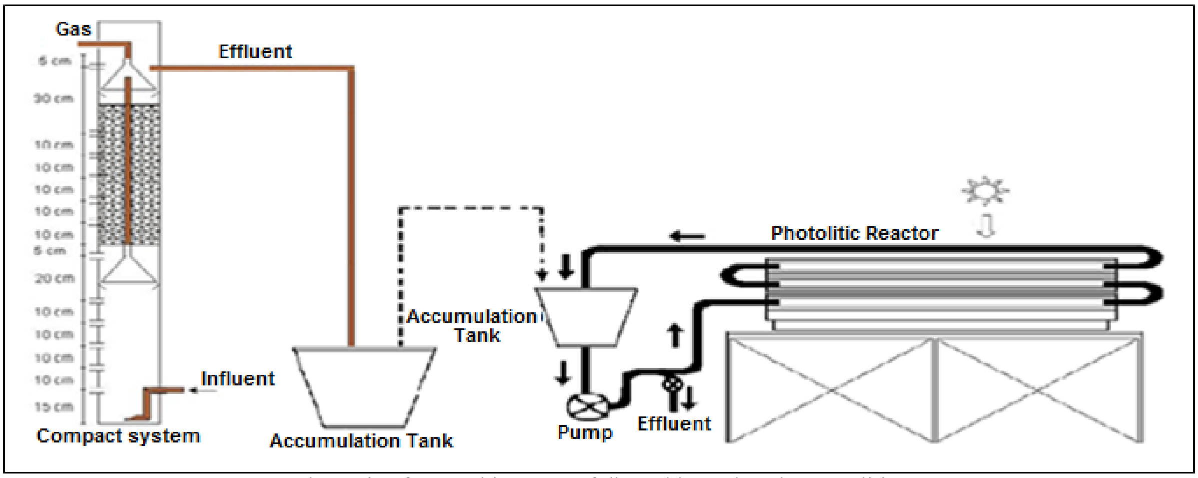

Fig. 1 Schematic of anaerobic reactor followed by Solar Photocatalitic Reactor

first consisted of a compact system (hybrid) comprised of anaerobic coupled UASB and anaerobic submerged filter with support medium made of cuboids plyurethane synthetic fiber sponges, each cube with a volume of 2 cm^3, occupying 3% of the volume of filter media, built in PVC with 20 cm diameter, effective height of 1.65 m and volume of 52 L, monitored with Hydraulic Detention Time (HDT) of nine hours

The second unit consisted of a photolytic reactor, solar parabolic cylindrical model (PTR, Parabolic through Reactor). The photolytic reactor consisted of a metal device about 70 cm by 180 cm in width and 76 cm high, provided by a mobile adjustable aluminum rods manually adjusted to 15° every hour, so as to concentrate the sun's rays by three half-parabolas of aluminum mounted below three glass tubes (Pyrex ®) with 1.50 m in length and 2.5 cm in diameter and volume of 2.205 L. The photolytic reactor operated in batch regime with a volume of 14.0 L during four hours from 10:00 to 14:00 h, recognized as the period of highest incidence of solar radiation, and probably a higher incidence of UV rays. The system was equipped with a container of equalization, and a centrifugal pump with a flow rate of 11.620 L/min which recirculated the effluent in batches of 4 hours. According to **Eq. (1)**, the exposure time in the hydraulic photolytic process corresponded to 0.63 hours. **Table 1** shows the main physical and operating of the system used:

$$\theta_{irr} = \theta_{total} \cdot \frac{V_r}{V_t} \quad (1)$$

θ_{irr}: hydraulic Exposure time in photolytic process (hours);
V_r: reactor volume (liters);
V_r: wastewater volume treated (liters);
θ_{total}: batch period (hours).

Table 1. Operational parameters of the studied systems.

Parameters	Anaerobic system	Photolytic Reactor (1)
Volume (L)	52.0	14.0
TDH (h)	9.0	4.0
Flow (L/d)	139.0	14.0
Volumetric organic load (VOL) (kg COD/m^3 d)	1.52	

(1): photolytic reactor was operated in batch, with a cycle of 4 h/d

The anaerobic system was powered by a pulse pump with a flow rate of 5.8 L/h and hydraulic retention time (HRT) of 9.00 hours, cell retention time of 90 d and organic loading rate (OLR) applied of 1.52 kg COD/ m^3 d.

Samples for microbiological analysis of effluents (fecal coliform) were collected in sterile containers (Amber type). The containers were removed from the oven the same day of sampling, listed according to the effluent collected and date of collection. The analysis was preceded immediately after collection.

For helminthes eggs examination, it was used the modified method Bailenger (WHO, 1989). The materials used for the analysis were: optical microscope common objective with 10X and 40X brand MEIJI; Centrifugal brand Sublime model BL 206; shaker-type Vortex brand Thermolyne Max Mix Plus model; Board of McMaster; common pipettes; Volumetric pipettes, Pasteur pipettes, tubes Nesseler; rack for Nesseler tubes; buckets with capacity of 2 liters, and siphoning hose and densimeter. The solutions used were: distilled water solution Triton X-100 and Tween 80, pH 4.5 buffer solution; PA Ethyl acetate and zinc sulfate solution with density 1.18.

Alkalinity determinations were performed by the method Kapp (1994) *apud* Buchau (1998), while all other tests followed the recommendations of the Standard Analytical Methods (APHA, 1998)

Regarding the analysis of the photolytic reactor, solar radiation intensity was measured with the aid of a radiometer VLX Cole-Par Mer Instruments Co. 9811 series with a photoelectric cell for direct measurement of UV radiation of 365 ± 2 nm, each 15minutes. For tests of photoreactivation the effluent was packaged in amber glass for 24 hours for subsequent analysis of Thermotolerant Coliforms (TTC).

Table 2. Efficiency average and standard deviation of the monitored parameters.

Parameters	Anaerobic system		
	Influent	Effluent	Efficiency (%)
pH	7.2 ± 0.3	7.8 ± 0,3	-
Raw COD (mg O_2/L)	380 ± 88	114 ± 48	70
Filtrada COD (mg O_2/L)	152 ± 50	85 ± 18	44
TSS (mg/L)	180 ± 88	22 ± 10	88
VSS (mg/L)	145 ± 58	20 ± 10	86
Turbidity (NTU)	-	21 ± 18	-
Ammonium-N (mg NH_4^+-N/L)	45 ± 12	48 ± 11	-
Total Phosphorus (mg P/L)	8.4 ± 2.1	7.8 ± 2.1	-
Orthophosphate (mg PO_4^{-3} –P/L)	6.2 ± 1.7	6.4 ± 1.8	-
Alkalinity (mg.CaCO/L)	360 ± 58	400 ± 59	-
C thermotolerant (CFU/100mL)	3.4×10^6	2.1×10^5	93, 823

NTU: Nephelometric Turbidity Units.

RESULTS AND DISCUSSION

Anaerobic System

In **Table 2** operational parameters of the anaerobic system are presented been acquired from 28 determinations for 210 d of operation including the mean, standard deviation and removal efficiency.

The anaerobic compact system obtained removal of total COD and filtered of 70% and 44% respectively (**Table 2**). Santos (2010) using a similar support media, although applying separate operating reactors, UASB followed by anaerobic filter obtained removal of 72 and 49% respectively. Busato and Pawlowsky (2005) obtained a removal efficiency in UASB followed by anaerobic filter of 72% been the complementary removal in the filter of 29%. Thus, the efficiencies presented by other researchers dealing with sewage in UASB anaerobic filter were similar.

Regarding the combined anaerobic filter, the limiting factor for this technology has also been the choice of alternatives for support media. In this case, the polyurethane behaved as a promising material occurring proliferation and fixation of microorganisms during the monitoring process. However it was observed an initial accommodation of the support media during the system feeding. The criteria and design parameters for hybrid system (UASB and anaerobic filters in this setting are not well defined, and still require further investigations. Despite all these difficulties, the fact is that the effluent coming from the anaerobic system was free of helminthes eggs and presented a clarified appearance, low concentration of organic matter, especially dissolved (20 mg VSS/L) and average turbidity of 21 NTU. These low concentrations of suspended solids facilitated the disinfection in photolytic process.

Helminthes Eggs Removal

With respect to helminthes eggs, 20 determinations were performed for raw sewage and effluent from the anaerobic system. **Table 3** shows the average concentration values (eggs/L) and frequency of helminthes eggs during the experimental period.

According to data from the effluent of the anaerobic system presented in **Table 3**, the removal of helminthes eggs in the anaerobic filter coupled to the UASB reactor was efficient because it is composed of a layer of support media made of polyurethane cubes with 2 cm side, where has occurred the proliferation and attachment of microorganisms. The high surface area to adherence, as well as the setup of polyurethane media was sufficient to provide good flow distribution, performing filtering and percolation through the support media, allowing the removal of helminthes eggs also aided by decanting, because of the sizes and sufficient eggs densities.

Table 3. Helminthes eggs Mean concentration and frequency found in affluent and effluent during the experimental period

Species	RW		Anaerobic System Effluent
	Eggs/L	%	Eggs/L
Enterobius vermicularis	35	19,45	ND
Ascaris lumbricoides	58	32,23	ND
Trichiuris sp	3	1,67	ND
Entamoeba sp	8	4,45	ND
Taenia sp	4	2,2	ND
Ancilostoma sp	72	40	ND
Total of eggs/L	180	100	ND

ND: Not Detected

Disinfection by Photolytic process

Table 4 shows values of 19 determinations of TTC concentrations of the influent for four (4) months operating the photolytic reactor as well as data on the effluent turbidity and variations of temperature, UV intensity and applied solar radiation dose.

The average intensity of UV radiation applied in 19 batches monitored according to data presented in **Table 4** ranged from 1.82 to 3.00 mW/cm^2. Elkarmi *et al.* (2008) confirmed that UV radiation ranging from 2.3 to 2.7 mW/cm^2 was sufficient to maintain an efficiency of 99.9998% removal of E. coli present in water with high turbidity of 16 NTU. The concentration of TTC in the influent ranged from 9.0 .10^5 UFC.100 mL^{-1} to 1.1. 10^7 CFU. 100 mL^{-1} with removal efficiency of fecal coliform of 99.9999%.

The initial temperature of the influent varied from 25 to 28 ° C and the effluent after each batch of four hours per day with recirculation ranged from 34 to 49 °C and an average turbidity of 21 NTU. The efficiency in the decay of pathogens to reduce turbidity exceeds 5 NTU (Elkarmi *et al.*, 2008).

The effluent presented good sanitary quality, with 90% of the samples thoroughly disinfected while the other fraction showed a concentration of TTC organisms up to 100 CFU. 100 mL^{-1}. It is worth mentioning that the variation in temperature was 25 to 35 °C (**Table 4**), less than the variations in the other experiments (25 - 49 ° C). According to some authors, the temperature exerts a synergistic effect with UV, which alone seems unable to inactivate microorganisms (Elkarmi, *et al.*, 2008).

Accordingly to data in **Table 4**, the penultimate experiment was submitted to the lower cumulative dose 4,196 mWs. cm^{-2} and a higher standard deviation in intensity (1.28), showing high variation in intensity compared to the others, probably because of atmospheric attenuation periods with a lower stroke incidence, which led to a lower efficiency in disinfection, been, as Mamame (2008) affirmed, a disadvantage of using sunlight as a disinfectant agent.

Only one from the 19 experiments presented in **Table 4** underwent to photoreactivation, was reactivated by maintaining a population of surviving microorganisms to disinfection after 24 hours of rest between 100 and 200 UFC/100 mL. This amount of reactivated TTC remained below the limit set by WHO for unrestricted irrigation (WHO, 2006). This success can be attributed to the inactivation spectrum offered by the sun in the disinfection process that damages not only specifically the nucleus but other organelles and bacteria proteins.

Figure 2 shows the behavior of TTC concentration decay as a function of exposure time. It is observed that during the first hour of exposure the same order of magnitude of 10^6 CFU/100 mL was maintained only occurring a significant decay after 140 minutes of exposure time. This observation guided the exposure time hydraulic for the effluent treated.

Disinfection Effect depending on the dose and temperature

Figures 3 and **4** were constructed from the geometric mean of the determinations made during the experiment, dealing respectively with the bacterial decay in relation to the applied dose of radiation and temperature occurred during the exposure time in the photolytic reactor effluent.

It is observed from **Fig. 3** that the decay of Thermotolerant Coliforms was significant from a applied dose around 3 000 m.W.s/cm^2. The applied ultraviolet irradiation dose is a crucial parameter in microorganism's inactivation process. As the dose is the product of radiation intensity by the exposure time, the inactivation can be achieved in the time interval smaller or larger depending on UV intensity (mW/cm^2) at the exposure site.

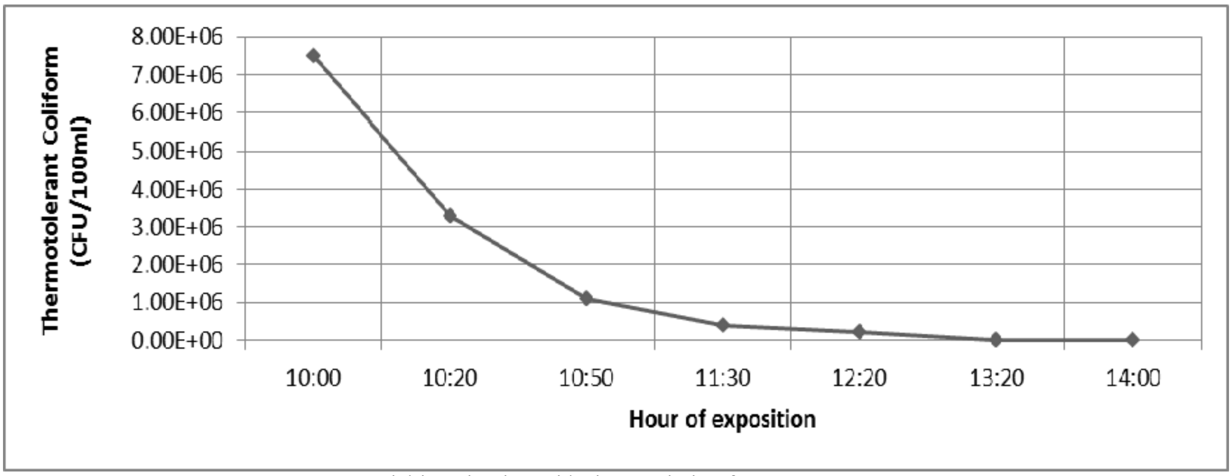

Fig. 2. Bacterial inactivation with time variation from 10:00 am to 2:00 pm

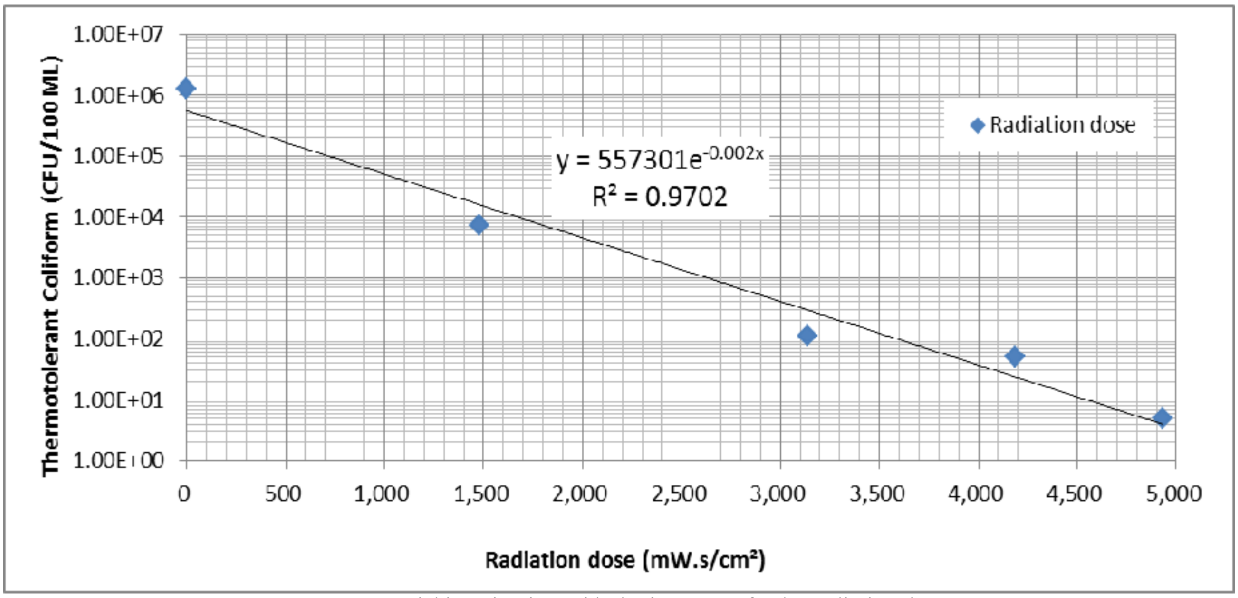

Fig. 3. Bacterial inactivation with the increase of solar radiation dose.

Table 4. Thermo Tolerant Coliform (TTC) Influent and effluent Concentration and variation of temperature, radiation intensity and dose.

Influent (CFU/100mL)	Influent Turbidity (NTU)	Temperature	Radiation Intensity (mW/cm^2)		Dose (mWs/cm^2)
		Initial - Final	Average	Std. Dev.	
9.0×10^6	10	28°C–49°C	2.65	0.59	6010
1.1×10^7	14	26°C–45°C	2.37	0.77	5365
9.9×10^6	9	25°C–46°C	2.50	0.85	5670
9.2×10^6	14	26°C–48°C	2.46	0.7	5579
9.0×10^5	8	25°C–49°C	2.50	0.83	5670
8.0×10^6	33	26°C–48°C	2.21	0.83	5012
9.0×10^6	18	25°C–48°C	2.66	0.89	6032
4.8×10^6	14	26°C–47°C	1.89	0.68	4268
9.0×10^5	15	25°C–46°C	3.00	1.00	6804
4.3×10^6	18	26°C–47°C	2.22	1.00	5035
8.0×10^6	16	25°C–45°C	1.85	0.86	5443
9.2×10^6	18	26°C–49°C	2.16	0.66	4899
8.0×10^6	31	25°C–47°C	1.82	0.63	4241
9.4×10^6	32	25°C–47°C	2.58	0.89	5851
7.9×10^6	23	25°C–45°C	2.48	0.78	5624
9.0×10^5	21	25°C–49°C	2.26	0.80	5125
4.8×10^6	15	25°C–45°C	2.43	0.91	5511
8.7×10^6	36	25°C–34°C	1.85	1.28	4196
8.3×10^6	38	26°C–35°C	2.00	0.89	4536

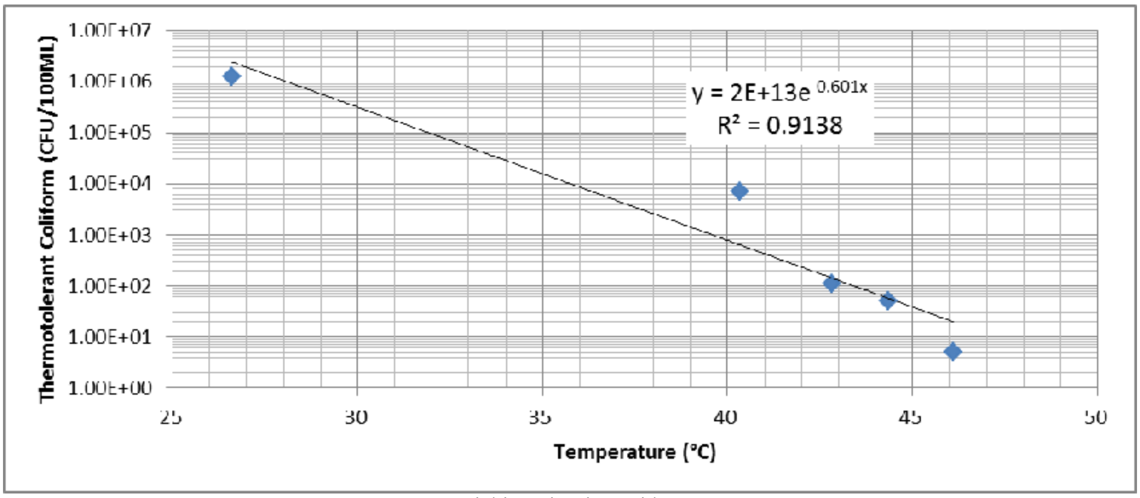

Fig. 4. Bacterial inactivation with Temperature.

The effect on the effluent disinfection by UV radiation on microorganisms is a function of dose intensity, temperature and turbidity. Even with the monitoring of the samples batch time, the radiation intensity varied significantly affecting the exposure time, and therefore, influencing the dose.

As shown in **Fig. 4** for temperature above 40 °C was observed a increase in the inactivation rate, indicating a synergistic effect for TTC decay that, in turn, occurred when the temperature reached 45°C. According to some authors, the temperature exerts a synergistic effect with UV, which means that alone, the UV is not able to inactivate microorganisms, but it's effect is amplified significantly for temperatures above 40°C (Abu-Ghararah, 1997; Meierhof *et al.* 2002; Elkarmi, *et al.*, 2008).

Although UV disinfection has been known since the nineteenth century, its implementation has virtually disappeared with the evolution of chlorination. However, for semi-arid region, application of solar UV disinfection of effluent with low concentration of suspended solids should be encouraged. Concerning the photo reactor, the material must have high transmissivity of UV rays and durability. The ordinary glass is not suited because of iron´s substance present in its constitution and also UV rays absorbance. Therefore, a better suited glass should be those with low iron content, for example, Borosilicate.

CONCLUSIONS

The compact anaerobic system produced a clarified effluent free of helminthes eggs, presenting also low concentration of organic matter, especially dissolved (20 mg SSV/L). These low concentrations of suspended solids facilitated the photolytic disinfection process, producing a good quality sanitary effluent, of which 90% of the samples were thoroughly disinfected, while the other fraction showed TTC concentration equal or less than 100 UFC/100 mL and high nutrient concentration (48 mg . NH_4^+-N/L and 6.4 mg PO_4^{-3}-PL^{-1}) and can be used for irrigation for productive purposes.

The efficiency of solar disinfection of anaerobically pretreated sewage in the photolytic reactor can be affected by temperature, applied dose, turbidity and local climatic factors, requiring longer time of exposure.

The photoreactivation was insignificant, yet remaining within the recommendations required by law. The temperature increase, in turn, positively affected the efficiency of disinfection.

The compact system with UASB conjugate with an anaerobic filter followed by photolytic reactor requires relatively simple operation without energy consumption, resulting in a significant reduction in operational costs of sewage treatment, and, indeed, a sustainable alternative for developing countries of tropical climate.

The times of exposure to ultraviolet radiation of 38 minutes was sufficient to achieve the inactivation of TTC to 6 log units. It is noteworthy that the intensity of solar UV radiation ranged from 2.0 to 2.3 mW/cm².

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