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ORIGINAL ARTICLE

Application of Slow Sand Filters for the Decontamination of Effluents from Oxidation Lagoons

Aplicación de filtros lentos de arena para la descontaminación de efluentes de lagunas de oxidación

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Carlos M. Martínez-Hernández[I]*, Jesús A. Sánchez-Jassa[II], Nilda Rosa Martínez-Flores[III], István Gómez-Ríos[I]

[I]Universidad Central “Marta Abreu” de las Villas. Santa Clara, Villa Clara, Cuba.
[II]Grupo Azucarero AZCUBA, Sata Clara, Villa Clara, Cuba.
[III]Ministerio de Salud Pública (MINSAP), Centro Provincial de Higiene y Epidemiologia, Santa Clara, Villa Clara, Cuba.

ABSTRACT: Using slow sand filters on a small scale, their decontaminating effect was tested. The work was carried out with the objective of eliminating the contamination of the effluents from the oxidation lagoons of two sugar mills "Carlos Baliño" and "Melanio Hernández". The effluents were taken in the central region of the country (Santo Domingo, Villa Clara and Tuinicú, Sancti Spíritus). The decontaminating effect of effluents from oxidation ponds after their passage through a slow sand filter in cascades was tested for different investigated treatments. The effluents were diluted in distilled water in the following proportions: T1 (10%), T2 (25%), T3 (50%), T4 (75%), T5 and T6 (undiluted). In the effluents, the following were determined: their physical-chemical and microbiological characteristics, before and after their passage through the slow sand filters. In most of the effluents evaluated, both their physical-chemical characteristics and the microbial load showed a notable reduction; obtaining values below the indicators allowed by current Cuban standards (NC-27: 2012; NC-1095: 2015 and NC-855: 2011).

Keywords: Oxidation Ponds, Physical-Chemical and Microbiological Characteristics, Slow Sand Filters.

RESUMEN: Utilizando filtros lentos de arena a pequeña escala se probó su efecto descontaminante. El trabajo se realizó con el objetivo de eliminar la contaminación de los efluentes de lagunas de oxidación de dos Centrales Azucareros “Carlos Baliño” y “Melanio Hernández”. Los efluentes fueron tomados en la región central del país (Santo Domingo, Villa Clara y Tuinicú, Sancti Spíritus). Se probó el efecto descontaminante de efluentes de lagunas de oxidación posterior a su paso por un filtro lento de arena en cascadas ante diferentes tratamientos investigados. Los efluentes fueron diluidos en agua destilada en las siguientes proporciones: T1(10%), T2(25%), T3 (50%), T4 (75%), T5 y T6 (no diluidos). En los efluentes, se determinaron: sus características físico-químicas y microbiológicas, anteriores y posteriores a su paso por los filtros lentos de arena. En la mayoría de los efluentes evaluados, tanto sus características físico-químicas, como en la carga microbiana se obtuvo una reducción notable; obteniendo valores por debajo de los indicadores permitidos por las normas cubanas vigentes (NC-27: 2012; NC-1095: 2015 y NC-855: 2011).

***Palabras clave*:** lagunas de oxidación, características físico-químicas y microbiológicas, filtros lentos de arena.

INTRODUCTION

The slow sand filtration has been broadly used as method to improve the quality of the water in different regions of the planet, due to its simplicity in the operation and to its numerous advantages. In the last decades, they have been implemented to improve the conditions of the water after meteorological events and natural disasters, when the treatment is truncated by the traditional methods of water potability or for its individual domestic use, having great acceptance. It has been demonstrated that the slow sand filters have worked in a successful way in urban and rural areas around the world, many of which subsist in a precarious way, but allowing improvements in public health and in the quality of the inhabitants' life of these areas. The good operation and the positive impact of this type of technologies have been evidenced.

*Author for correspondence: Carlos M. Martínez-Hernández, e-mail: carlosmh@uclv.edu.cu

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In recent investigations Francesena (2016); Villareal (2017); Brito *et al.* (2019); Fabregat (2019); Llama (2019); Sánchez (2020), it has been evaluated the method of slow sand filtration like alternative to obtain not very aggressive effluents of oxidation lagoons to the environment, with local materials diminishing costs and offering an alternative before the current conditions of these effluents, which are poured to the environment with high value of contamination. Some of these studies, have referred to the implementation of slow sand filters systems to laboratory scale with the purpose of improving the effluents of oxidation lagoons, for, later on, measuring certain parameters of the effluents and comparing them with the Cuban norm NC-27: 12 (2012) of residual water and NC-855:11 (2011) for the use of the residual of the sugar cane industry to irrigate the sugar cane. In the investigations indexed previously, it has been able to verify that the slow sand filters were a good alternative to improve the quality of the biodigesters effluents, obtaining high percentages of removal of chemical oxygen demand (COD), biological oxygen demand (BOD_5), total solids (TS), fecal coliform, total coliform and *pseudomonas aeruginosas* in recent investigations envelope at national and international level.

Motivated by some of the investigations referred previously and like part of an investigation project in course of the Agricultural Engineering Department of "Marta Abreu" Central University of Las Villas, which has been of interest for "Carlos Baliño" sugar mill, it was decided to carry out, in the central region of Cuba (provinces of Villa Clara and Sancti Spíritus), the study and valuation of effluents of the oxidation lagoons of "Carlos Baliño" and "Melanio Hernández" sugar mills. Because it is a significant area that reflects the current situation of the use of effluents from oxidation lagoons, the results obtained in this investigation could be used as base to develop future engineering projects that offer another type of solutions to the outlined problem (great proliferation of oxidation lagoons in the central territory of Cuba, as well as the occurrence of atmospheric phenomena of great magnitude in the last decade). That shows these effluents are dangerous since they can contaminate superficial and deep waters as they are poured indiscriminately to the environment without any type of previous treatment. Based on that, the objective of this work was to evaluate the effect of slow sand filters for the improving of effluents of the oxidation lagoons of "Carlos Baliño" and "Melanio Hernández" sugar mills with different dilution percent in water.

MATERIALS AND METHODS

Production of Biofilter of Gravel, Sand, Zeolite and Vegetable Coal. Hydraulic Rehearsals

The making of the biofilter to laboratory scale was carried out with materials from territories of Villa Clara and Sancti Spíritus provinces, mainly following some of the approaches obtained in the bibliographical revision, like mean size of the particles of the materials utilized, which are referred later on in this epigraph.

Materials

The materials used are of own acquisition and for them, 3 plastic tanks of high-density polyethylene (PAD) of 5 L were used, each one filled with the respective materials: the first one was loaded with washed sand, the second with zeolite and the third with gravel and vegetable coal. The heights of the filtering mediums were 8, 8 and 16 cm, respectively. In tank 1, a quantity of 2000 cm^3 of washed sand was added,in tank 2, a quantity of 2000 cm^3 of zeolite was added, while in tank, 3, 3000 cm^3 were added (2000 cm^3 of gravel + 1000 cm^3 of vegetable coal).

Initial Sampling

Calculation of the Contact Bed Thickness

The head loss (ie pressure drop) that occurs when clean water flows through clean filter media can be calculated from known equations. Flow through a clean filter of ordinary grain size (ie 0.5 mm to 1.0 mm) to ordinary filtration. The velocities (4.9 to 12.2 m/h) would be in the range of laminar flow represented by the Kozeny equation that is dimensionally homogeneous (that is, any consistent unit that is dimensionally homogeneous can be used) according to Letterman, (2010). But as the water to try is not clean, a simpler calculation was kept in mind and it was performed by the equation of Darcy (1) adapted to a filter Sánchez (1997).

$$(H1 - H2) = \frac{vf}{k} \times \mathrm{L} \quad (1)$$

Where:

L = thickness of the layer of sand, cm

K or Kf = filtration coefficient

H1 = hair of water raw or to be treated, cm

H2 = hair of treated water, cm

vf = filtration velocity in the channel of sand, cm^3/s

Design Flow of the Filter

With the velocity of filtration of the samples and the area of the filter the design flow was calculated through the following equation:

$$Q = A \times vf \quad (2)$$

Where:

Q = flow, m^3/s;

A area of the section, m^2;

vf = velocity, m/s.

Physical-Chemical Analysis of the Effluents

The samples investigated were transported to the laboratories of the Center of Chemical Bioactivos (CBQ) of the Central University of Las Villas (UCLV) and to the National Enterprise of Analysis and Technical Services (ENAST), of Santa Clara, Villa Clara, for the determination of the parameters object of study. In all the cases, three measuring were evaluated for each variable which were temperature, pH, electric conductivity (EC), solid soluble total (TSS), chemical oxygen demand (COD), biological oxygen demand (BOD_5) and the microbial load per treatment evaluated in each one of the oxidation lagoons analyzed. These samples were characterized according to the approaches specified by the Cuban norms NC-855:11 (2011) y NC-27: 12 (2012). -The effluents were analyzed at the outlet of the oxidation lagoons and later when passing through the slow sand filters that act in three cascades (gravel filter + vegetable coal; sand+zeolite filter; sand filter).

Determination of the Microbial Load in the Effluents

The effluents were collected in plastic bottles of 1500 mL, and they were taken quickly to the laboratory of microbiology of the Provincial Center of Hygiene and Epidemiology of Santa Clara, Villa Clara, where total coliformes, fecal coliformes and *pseudomonas aeruginosas* were determined, at the outlet of the oxidation lagoons and later when passing through the slow sand filters. The obtained values were contrasted with the values specified by the Cuban norms (NC-855:11, 2011; NC-27: 12, 2012; NC-1095-15, 2015).

RESULTS AND DISCUSSION

Filter Design

Screen Analysis

Taking as reference the studies of Villareal (2017), it is assumed that the screen analysis of the fraction of sand of Arimao and of the zeolite, using the series of sieves ASTM D 2434 (1997), it is similar to the utilized one in this work, in which the same materials were used. With the previous analysis, it can be concluded that the washed sand and the zeolite have a grain distribution accepted for the construction of the biofilters.

Flow of Design of the Filter

Taking like reference the slow sands filters executed by Fabregat (2019), with the samples velocity of filtration and the area of the traverse section of the filter outlet, the design flow is calculated by means of equation 2. Substituting values in equation 2, the following is obtained:

$$Q = 3{,}8 \cdot 10^{-8} m^3/s$$

For the determination of the flow of design of the filter common water was used as fluid, nevertheless, it was also determined in all the investigated effluents. The velocity of the real fluid was taken as an average of the values determined to scale reduced in the effluents investigated at the outlet of the slow sand filter and it was 0,25 cm^3/s.

Calculation of the Thickness of the Contact Bed

Substituting in the equation of Darcy (1) adapted to a filter, it is obtained that:

$$L = 3{,}12 \text{ cm}$$

The thickness of the contact bed was assumed L = 8 cm, practically double of that determined by calculation, in order to obtain good filtrates of the effluents which were very polluted fluids.

Analysis of the Physical-Chemical Parameters

Water Temperature

A mercury thermometer was used to measure temperature and it was carried out before and after the process of water filtration. The obtained results are presented in Table 1.

It is possible to observe (Table 1) that water temperature of the effluents of "Melanio Hernández" Mill diminish from 28,8 up to 27,0 ºC, while water temperatures of the effluents at "Carlos Baliño" Mill after the filtration process oscillate between 23,6 and 25,8 ºC , lower values due to its passing through the

TABLE 1. Comparison of temperatures before and after effluents filtration

Treatment Effluents (%) dilution	"Melanio Hernández" Mill Effluents	"Carlos Baliño" Mill Effluents	Temperature before filtration (ºC)	Temperature after filtration (ºC)
10	T1 MH	T1 CB	25,9 (25.9)	28,7 (23,8)
25	T2 MH	T2 CB	28,0 (28.0)	28,6 (23,6)
50	T3 MH	T3 CB	28,8 (28.8)	28,9 (23,6)
75	T4 MH	T4 CB	28,4 (28.4)	27,0 (23,6)
No diluido	T5 MH (n.d)	T5 CB (n.d)	28,6 (28.6)	27,3 (25,8)

Legend: *n.d. not dilute; CB-Carlos Baliño; MH-Melanio Hernández; value between parenthesis refer to Carlos Baliño Mill effluents.*

interstices, property that the water acquires and makes it more acceptable to the palate (in drinking water) and that allows the decrease of the present microorganisms in it, since the decrease of the temperature influences in the proliferation of these biotic annulling the reproduction processes. According to Torres (2015) the obtained values are in the range of good temperatures (25 to 35 ^{0}C).

COD Analysis

In the Table 2, this variable is analyzed according to NC-27: 12 (2012) and effluent CODs from sampling before and after filtration, are compared.

In Table 2, it is observed that all treatments fulfill the Cuban norm NC-27: 12 (2012) once effluents have passed through different filters. Slow sand filters show a good effect as they reduce or maintain the COD values, except in treatment T3. According to Torres (2015), the quantity of oxygen dissolved is one of the critical values to control in biological reactors.

BOD$_5$ Analysis

In Table 3, a comparison between BOD$_5$ from effluents before and after bio-filtration is shown.

In Table 3, a BOD reduction is observed in the treatments T3 and T4, similar value is kept in T5 treatment and an increase is produced in treatments T1 and T2 after the filtration process, which confirms the good work of the slow sand filters. According to Torres (2015), this indicator allows measuring the effectiveness in different purification processes and carrying out adjustments.

pH and Conductivity Analysis

In Table 4, the results of pH measuring before and after filtration are shown.

In Table 4, a slight increase of pH values is observed in all treatments, except in T4. When they are compared to the Cuban norm NC-855:11 (2011), for their application to irrigate, it is defined that, treatments T1 and T2 should not be used. According

TABLE 2. Comparison of COD before and after bio-filtration

Treatment Effluents diluted (%)	COD (mg L^{-1}) Before	COD (mg L^{-1}) After	Maximum limit
T1 CB (10)	118	118	<700
T2 CB (25)	118	118	<700
T3 CB (50)	118	**177**	<700
T4 CB (75)	118	73	<700
T5 CB (n.d)	118	88	<700
T6 MH (n.d)	n.e	n.e	<700

Legend: n.d. not diluted; n.e- not valued.

TABLE 3. Comparison of the BOD$_5$ before and after bio-filtration

Treatment Effluents diluted (%)	BOD$_5$ (mg L^{-1}) Before	BOD$_5$ (mg L^{-1}) After	Maximum limit NC-27: 12 (2012)
T1 CB (10)	**54**	**59**	**<300**
T2 CB (25)	**54**	**88**	**<300**
T3 CB (50)	54	36	<300
T4 CB (75)	54	44	<300
T5 CB (n.d)	54	54	<300
T6 MH (n.d)	n.e	n.e	<300

Legend: n.d (not diluted); n.e (not valued).

TABLE 4. Analysis of pH measuring before and after filtration

Treatment Effluents diluted (%)	pH		
	Before	After	NC-855:11, 2011
	Effluents	Effluents	pH
T1 CB (10)	7,80	8, 82	Not to use
T2 CB (25)	7,98	8, 58	Not to use
T3 CB (50)	7,79	8, 33	Bad
T4 CB (75)	7,98	7, 36	Regular
T5 CB (n.d)	7,43	7, 92	Bad
T6 MH (n.d)	7,00	7, 80	Regular

Legend: n.d (not diluted)

to Torres (2015), pH of urban residual sewages oscillates between 6,5 and 8, the variations of these intervals are due to the lack of control of industrial dumping. In accordance with the Cuban norm NC-855:11 (2011), these effluents in the variable pH, can be classified between regular and bad, for their application to irrigate sugar cane.

In Table 5, the electric conductivity and total soluble salts values before and after filtration are presented.

In Table 5, in the variable electric conductivity (E.C), it is observed that treatments T2, T4, T5 and T6 (classified as good) after passing through the slow sand filters, they comply the Cuban norm NC-855:11 (2011), differently from treatments T1 and T3 which are classified as regular. Vázquez y Torres (2006), refer that the fundamental factors affecting saline adsorption are temperature, light, concentration of hydrogen, oxygen concentration, interaction of mineral elements, growth, concentration of mineral salts and content of water in the soil. For that reason, the results obtained here, are in correspondence with these authors and they reaffirm the good work of the slow sand filters. According to Torres (2015) normal values of conductivity in urban waste waters oscillate in the range of 0,500 to 1,500 (µS/cm). In the case of the variable total soluble salts (TSS), an increase was presented from 363 up to 895 mg L^{-1} as the degree of dilution was increased, but all cases agree with the Cuban norm NC-855:11 (2011), that limits it to <960 mg L^{-1} even for the not diluted sample.

Determination of Real Permeability:

By means of timing, the real permeability was determined in the effluents investigated, according to the filters utilized as models. Table 6 shows the results.

It is shown that permeability values in filter No.1, developed a variation from 5,86 to 7,66 being in correspondence with the range of theoretical values outlined by Villareal (2017).In the case of filter No.2, the values oscillated between 0,30 up to 2,53 and were above the theoretical ones. While in filter No.3, the values oscillated from 0,22 to 0,78 with some values inside the theoretical range outlined by Villareal (2017).The above-mentioned could be related with the characteristics of the materials utilized for filtering.

Analysis of Filtration Coefficient (kf)

The values determined by (Villareal, 2017) are assumed for the present study. That author refers the results of the filtration analysis from the materials to load for a cylinder height of 17,50 cm, th depth of the stone reaches 1,20 cm, to obtain a filtration coefficient (kf) of Arimao sand of 0,0936 cm^3/s. In this work the real permeability indexes were determined, which are shown in Table 6.

For the case of the zeolite, the same conditions were kept, obtaining a coefficient of 0,0978 cm^3/s. That can be related to the grain of the zeolite, which is bigger and, for that reason, the size of the interstice allows a quicker filtration of the fluid.

TABLE 5. Electric conductivity and total soluble salts values before and after filtration.

Treatment Effluents diluted (%)	Electric conductivity (µS/cm)	Electric conductivity (µS/cm)	Total soluble salt (TSS) ppm	Total soluble salt (TSS) ppm
	Before	**After**	**Before**	**After**
T1 CB (10)	1,372	**1,70**	>960	363
T2 CB (25)	1,230	1,07	>960	587
T3 CB (50)	1,043	**1,56**	>960	727
T4 CB (75)	0,909	1,08	>960	895
T5 CB (n.d)	0,183	0,6	>960	959
T6 MH (n.d)	**2,280**	1	n.e	n.e

TABLE 6. Real and theoretical permeability

Treatment Effluents diluted (%)	Permeability, [cm^3/s]	Filter-F1 (Gravel + vegetable coal)	Filter-F2 (Zeolite)	Filter-F3 (Washed sand)
	Theoretical permeability	**3 to10 [cm^3/s]**	**0.0978 [cm^3/s]**	**0.4 to 0.01 [cm^3/s]**
	Real permeability	**[cm^3/s]**	**[cm^3/s]**	**[cm^3/s]**
T1 CB (10)		6,97	0,20	0,22
T2 CB (25)		7,66	0,18	0,17
T3 CB (50)		7,11	0,19	0,16
T4 CB (75)		6,75	0,20	0,22
T5 CB (n.d)		5,86	0,19	0,27
T6 MH (n.d)		7,24	0,43	0,48

Analysis of the Microbial Load in the Effluents

It is shown in Table 7.

The results of the microbial load (total and fecal coliforms) previous to the filtration process in the treatments analyzed, show a high contamination, above that specified in the (NC-1095-15, 2015). While the results obtained in *Pseudomonas areuginosas* before and after filtration stayed in the range established by the Cuban norm. Total and fecal coliforms after filtration decreased in treatments T1 and T2, while they stayed equal in the other treatments in reference to that specified by the Cuban norm NC-1095-15 (2015). That is in contradiction with previous works made by Martínez *et al.*, (2014; 2017); Sosa (2015); Martínez & Francesena (2018); Fabregat (2019).

CONCLUSIONS

- A slight increase of the pH values was observed in all the treatments, except in T4 (7,36). The pH behaved in values between 7,36 and 8,82. According to its comparison with the Cuban Norm NC-855:11 (2011), treatments T1 (8,82) and T2 (8,58) should not be used for its application to irrigate sugar cane. In the electric conductivity (E.C), treatments T2 (1,07), T4 (1,08), T5 (0,6) and T6 (1), classified as good after passing through slow sand filters, they comply the Cuban norm NC-855:11 (2011). Treatments T1 (1,70) and T3 (1,56), were classified as regular. This indicator behaved in the range from 0,6 to 1,70 µS/cm, reducing the saline content of the effluents notably.
- In the case of the variable total soluble salts (TSS), an increase was presented from 363 to 895 mg L^{-1} as the degree of dilution was increased, but all cases, even the not diluted sample, fulfilled the Cuban norm NC-855:11 (2011), that limits it to <960 mg L^{-1}.
- Water temperature of the effluents at "Melanio Hernández" Mill diminished from 28,8 to 27,0 ºC, while the effluents of "Carlos Baliño" Mill, after filtration oscillate between 25,8 and 23,6 ºC, allowing improving their quality. The COD began to vary moderately from 177 to 73 mg L^{-1} being smaller than that established by the NC-27: 12 (2012), which limits it to <700 mg L^{-1}.
- In the BOD_5 a notorious decrease was observed from 88 mg L^{-1} to 36 mg L-1, complying that specified by the NC-27: 12 (2012), which limits it to <300 mg L^{-1}.
- The treatment systems using slow sand filters allow diminishing the polluting load of the residual and they increase the efficiency as this it is filtered, allowing its dumping and use with economic ends.

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TABLE 7. Microbiologic analysis of the effluents analyzed before and after filtration.

Treatment Effluents diluted (%)	Total coliforms		Fecal coliforms		*Pseudomonas areuginosas*	
	(CFU/100mL)					
	Before	After	Before	After	Before	After
T1 CB (10)	>1600	**>1600**	>1600	7,8	12	1,8
T2 CB (25)	>1600	7,8	>1600	4,5	39	9,3
T3 CB (50)	>1600	**1600**	>1600	**1600**	39	27
T4 CB (75)	>1600	**> 1600**	>1600	**1600**	24	22
T5 CB (n.d)	>1600	**1600**	>1600	**1600**	26	1,8
T6 MH (n.d)	>1600	**1600**	47	**1600**	1,8	1,8

*Legend: *NC-1095: 2015. CFU: Total coliform < 1000 CFU/100 mL, fecal coliform < 1600 CFU/100 mL and Pseudomonas areuginosas < 1600 CFU/100 mL.*

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Carlos M. Martínez-Hernández, Prof. Titular. Universidad Central “Marta Abreu”de las Villas. Carretera a Camajuaní, km.5.5, CP: 54830. Santa Clara, Villa Clara, Cuba. Tel: 53-42-281692. Fax: 53-42-281608. e-mail: carlosmh@uclv.edu.cu.

Jesús a. Sánchez-Jassa, Ing. Agrícola, Grupo Azucarero AZCUBA, Sata Clara, Villa Clara, Cuba, e-mil: jesusjassa@nauta.cu.

Nilda Rosa Martínez-Flores, MSc., Inv. Ministerio de Salud Pública (MINSAP), Centro Provincial de Higiene y Epidemiologia, Santa Clara, Villa Clara, Cuba , e-mail: microbiologia@infomed.sld.cu.

István Gómez-Ríos, Profesor MSc., Universidad Central “Marta Abreu”de las Villas. Carretera a Camajuaní, km.5.5, CP: 54830. Santa Clara, Villa Clara, Cuba. Tel: 53-42-281692. Fax: 53-42-281608. e-mail: carlosmh@uclv.edu.cu.

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