Análisis del funcionamiento de la configuración del reactor anaerobio de flujo ascendente – filtro percolador para el tratamiento a escala real de aguas residuales domésticas

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Analysis of the performance of the upflow anaerobic sludge blanket - trickling filter configuration for treating domestic sewage at full scale

Anàlisi del funcionament de la configuració del reactor anaerobi de flux ascendent - filtre percolador per al tractament a escala real d'aigües residuals domèstiques

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SUMMARY

In addition of the existence of wastewater treatment plants (WWTP), it is necessary ensure their effectivity and sustainability over time through a proper selection of technologies, good design and construction and good practices of operating and maintenance. The configuration: UASB reactor followed for a Trickling Filter has demonstrated the obtaining of an effluent in line with the requirements of the environmental legislation. The Valle del Cauca-Colombia state has 19 WWTP and five has this configuration. Although the analysis realized in these WWTP shows weaknesses associated with inadequate selection of design criteria and deficiencies of operation and maintenance, it was found an adequate performance in terms of the removal efficiencies of COD, BOD5 and TSS (about 80%). Given the benefits of this configuration to treat domestic sewage, it is advisable to establish criteria of design, operation, and maintenance appropriate, what will result in greater capacity and efficiency of treatment.

Keywords: **Anaerobic/aerobic treatment; domestic wastewater; trickling filter; UASB.**

RESUMEN

Además de la existencia de plantas de tratamiento de aguas residuales (PTAR), es necesario asegurar su efectividad y sostenibilidad en el tiempo a través de una adecuada selección de tecnologías, buen diseño y construcción y buenas prácticas de operación y mantenimiento. La configuración Reactor UASB seguida de Filtro Percolador, ha demostrado la obtención de un efluente acorde con los requerimientos de la legislación ambiental; el Departamento del Valle del Cauca-Colombia tiene 19 PTAR y cinco de ellas presentan esta configuración. Aunque el análisis realizado a estas PTAR, muestra debilidades asociadas a selección inadecuada de criterios de diseño y deficiencias de operación y mantenimiento, se encontró un desempeño adecuado en términos de eficiencias de remoción de DQO, DBO5 y SST (alrededor de 80%). Dadas las bondades de esta configuración para el tratamiento de aguas residuales domésticas, es recomendable establecer criterios de diseño, operación y mantenimiento apropiados, lo que resultará en una mayor capacidad y eficiencia del tratamiento.

Palabras clave: **Agua residual doméstica; filtro percolador; tratamiento anaerobio/aerobio; UASB.**

RESUM

A més de l'existència de plantes de tractament d'aigües residuals (PTAR), cal assegurar la seva efectivitat i sostenibilitat en el temps a través d'una adequada selecció de tecnologies, un bon disseny i la construcció i bones pràctiques d'operació i manteniment. La configuració Reactor UASB seguida de filtre percolador, ha demostrat l'obtenció d'un efluent d'acord amb els requeriments de la legislació ambiental; el Departament del Valle del Cauca-Colòmbia té 19 PTAR i cinc d'elles presenten aquesta configuració. Encara que l'anàlisi realitzat a aquestes PTAR, mostra debilitats associades a la selecció inadequada de criteris de disseny i deficiències d'operació i manteniment, es va trobar un desenvolupament adequat en termes d'eficiències de remoció de DQO, DBO5 i SST (al voltant del 80%). Donades les bondats d'aquesta configuració per al tractament d'aigües residuals domèstiques, és recomanable establir uns criteris de disseny, operació i manteniment apropiats, el que resultarà en una major capacitat i eficiència del tractament.

Paraules clau: Aigua residual domèstica; filtre percolador; tractament anaerobi/aerobi; UASB.

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INTRODUCTION

In 2025, the world population will be about 7.2 billion people of which 2/3 would locate in cities [1]. In Latin-American and Caribbean (LAC) context, a big population percentage are located in urban centers, but the predominance of small population cities is remarkable (of 14000 municipalities, 90% has less than 50 thousand inhabitants and more than 30% has less than 5 thousand [2].

Figure 1a shows the worldwide domestic wastewater treatment - DWWT coverage context, being the regions of the developing countries the lowest coverage of recollection and adequate treatment [3]. Figure1b proves this tendency in LAC, as it is seen that in 21 countries analyzed, low coverage predominate, being the main causes financial aspects and the lack of knowledge about low cost alternative technologies, which compromises the sustainability, management and operation of wastewater treatment systems [4-6].

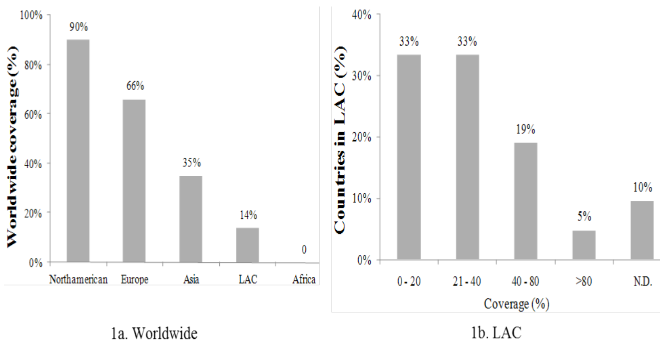

Figure 1. *Wastewater treatment coverage context. Source: Adapted from [3]*

DWWT is also of vital importance due to an increase in the scarcity of clean water, which makes it is necessary the appropriate management of available water resources [7]. Building a wastewater treatment system by itself does not mean a solution to environmental issues; to make this possible it is necessary to ensure effectiveness and sustainability over time through appropriate technology selection and system operation [8,9].

Selection of DWWT technologies depend on factors such as i) wastewater characteristics, ii) location's social and cultural traits, iii) the effluent's required quality according to its use or final destination, iv) land's availability, v) compatibility of the different operations and processes, vi) environmental impacts due to technology, vii) investment and operating cost of the treatment system, viii) reliability and ix) available means of evacuation for the final pollutants[10].

Despite the abundance of water resources in Colombia, their distribution is not uniform, because most of the population (74%) is concentrated in areas where offered superficial water is only 21% [11]. Of the 1097 cities that exist in Colombia, 43% have DWWTP (total 562).

Even though the seven DWWTP with flow > 500L/s represent only 3% of the total DWWTP (Figure 2), constitute 54% of the capacity installed in the country (flow design 18 m^3/s). Additionally, there are few cases where treatment coverage is 100% and of 72.2 m^3/s of wastewater generated by the urban population in 2010, only 31% (22,4m^3/s) was treated [11].

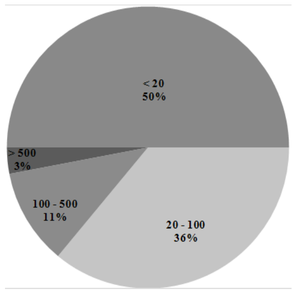

Figure 2. *Distribution of DWWTP by treated flow in Colombia (L/s). Source: Adapted from [11]*

Among technologies for DWWTP implemented in Colombia, the two most applied technologies are stabilization ponds and anaerobic systems [11], this situation is very similar with the tendencies on DWWT in developing countries [5] where tropical and subtropical climate conditions predominate with temperatures above 20°C. In these regions anaerobic technology is the most sustainable for the DWWT due to mainly aspects as simplicity and lower investment costs, low energy consume, high potential of methane generation and the nutrient approach of the treated wastewater and low sludge production and GHG emissions [6,12-14]; These traits make them particularly well suited for decentralized wastewater treatment, mainly in rural areas and small towns [15].

Despite the operational simplicity of stabilization pond systems, factors such as the high land cost and the consequences on the regional economy that means sacrificing high agricultural production areas [16], have led to the implementation of other treatment technologies more compact as anaerobic reactors alone or combined with aerobic systems [9,10,17-19]. Experiences at different scales have demonstrated that the treatment of anaerobic reactor effluents with aerobic processes allows to obtain better quality of treated effluent and economical advantages [20-28].

The UASB is the most anaerobic reactor implemented for treating DWW in the world [5-6]. The UASB followed by trickling filter (UASB/TF) would also ensure effluent quality in accordance with the requirements of the environmental legislation and it has allowed to meet three fundamental principles necessary to ensure implementation [14]: i) universal access, ii) efficiency and economic sustainability and iii) use of appropriate technologies considering the payment capacity of user and the adoption of gradual and progressive solutions. That configuration is usually capable of achieve COD, BOD_5 and TSS removal efficiency up to 91, 96 and 94% respectively [29-31]. Additionally, this configuration allows produce a renewable energy source such as methane and produce smaller amounts of sludge which is also stabilized in the same reactor.

Although not extensively reported in the literature, there are successful full-scale experiences in countries like Colombia, Brazil and Guatemala that have reported overall COD removal efficiencies above 80%. In Brazil, Aisse et al. [32] it was reviewed the DWWT that treats UASB reactor's effluents of the states of Paraná for populations between 200 thousand and 600 thousand inhabitants, among which (UASB/TF) configuration is included; Onça's DWWTP (Brazil) is considered the largest DWWTP in LAC with a treatment capacity of 1.8 m^3/s which may be expanded to 3.6 m^3/s [33]. In Egypt, a full-scale experience was presented [34], in which this configuration obtained removal efficiencies of 70% of COD and BOD_5 and of 86% of TSS. The department of Valle del Cauca is the Colombia's region where UASB/TF configuration is most implemented for the treatment of DWW; on this paper we intended to identify the advantages and limitations in the design, construction, operation, maintenance and performance of this configuration based on the theoretical knowledge and experience in other DWWTP under similar conditions.

METHODOLOGY

Identification of DWWTP

We initially identified the department's municipalities that use the UASB/TF configuration for treating DWW; then we compiled an overview related to demographics aspects (population, density and stratification and growth rate), utilities (water supply, sewage collection and disposal of solid waste, energy, telecommunications, coverage) and wastewater production (average and peak flows). In order to know the configuration, operation and maintenance of each DWWTP, information was requested regarding origins of the project, expected benefits, technology selection, maintenance activities, generation and product management, effluent quality, receiving bodies characteristics and the role of environmental authorities in developing the project.

Identification of critical issues of design, operation and maintenance

To define the critical issues in the design and operation & maintenance on the preliminary treatment, UASB reactors, trickling filter and final settler, calculation reports were reviewed to establish the design criteria of the treatment system units. Additionally, technical visits were made in order to identify the most relevant aspects of the construction, operation and maintenance. By reviewing the literature and comparisons with full-scale application at the same conditions (temperature, rainfall, sunshine) we identified identify the advantages and limitations.

WWTP performance evaluation

Given that environmental and population characteristics of the DWWTP evaluated are similar, performance evaluation was conducted by analyzing the results of 32 characterizations made in 3 DWWTP (Calima-Darien, Riofrío, Restrepo), that included measuring of pH, BOD_5, Total and Filtered COD, TSS, Total Kjeldahl Nitrogen (TKN) and Total Ammonia Nitrogen (TAN), which were determined according to Standard Methods [35]. The evaluation was performed using descriptive statistical analysis of average, median, maximum and minimum data, coefficients of variation and standard deviation. The results are presented in Boxplot graphs, in order to observe the variability in time, the existence of outliers and symmetry of distribution.

RESULTS AND DISCUSSION

Identification of DWWTP

SSPD [11] indicates that of 42 municipalities in the Department of Valle del Cauca, 18 have DWWTP (two in Cali), of which 17 have secondary treatment and the other two have advanced primary treatment. The predominant technology are the stabilization ponds and UASB/TF configuration with seven systems each one, followed by Chemical enhanced primary and high-rate Trickling Filter with two each system; the last technology is Septic tank/Anaerobic Filter [36-39].

Table 1 shows the main characteristics of the DWWTP that have UASB/TF [39]. According to information obtained, the municipalities where these DWWTP are located, the population varies between 8000 and 61000 inhabitants, considered small communities, classified as medium or low economic power and temperatures typical of tropical and subtropical climate [9,40,41]. These conditions show the technology selected as suitable for the regional context [5, 9,10,14,17-19].

Table 1. **Main characteristics of DWWTP evaluated.**
Source: HLR: Hydraulic Load Rate. Adapted from [39]

Item	Location				
	Restrepo	Calima-Darién	Riofrío	Pradera	Caicedonia
Design year	1995	2003	2003	2007	2006
GENERAL CHARACTERISTICS					
Start date of operation	1998	2007	2008	2010	2011
Design period (years)	10	20	20	20	20
Design population (inh)	8960	17284	11975	61089	43692
Design flow (L/s)	40,2	96	43,5	126,6	92,6
Operating temperature (ºC)	16 - 21	18	23	23	23
UASB CHARACTERISTICS					
UASB HRT (h)	8,5	8	8	8	11,5
UASB depth (h)	4	6,7	6	5,1	5,5
Biogas management	Gas burner – Flares				
TRICKLING FILTER CHARACTERISTICS					
TF HLR ($m^3/m^{2*}d$)	30	49,8	43,4	8,4	53,1
TF depth (m)	4				
Type of media	Plastic				
FINAL SETTLER					
HLR (m/d)	14				

Identification of critical issues of design, operation and maintenance

The treatment system include coarse and fine screens, grit chamber, grease trap, UASB reactors, trickling filter, final settler and sludge drying bed. With the revision of calculation reports and technical visits to the DWWTP, it was found that some units had adopted design criteria that do not match to those recommended in the literature. Table 2 show the critical points identified in the preliminary treatments in DWWTP.

Table 2. **Critical issues in preliminary treatment.**

Unit	Critical point	Impacts
Coarse and fine screens	Rectangular or circular bar shape	Often plugged, poor performance
	Solids accumulation in screen channel	Odor problems, poor performance
	Improper access for maintenance	
	Single unit: hinder maintenance	
Grit chamber	Inadequate design	Inorganic solid accumulation in UASB
Grease trap	Hydraulic jump, improper operation	Grease accumulation in UASB.

Source: [14,20].

Table 3 presents the critical issues found in UASB reactors. With the exception of two DWWTP, it is stress as a positive development the installation of tilted plates in the settling zone UASB reactor in order to promote the retention of solids. But it was observed considerable losses of biogas mainly due to inappropriate Solid-Liquid-Gas (SLG) separator design, construction and operation.

Table 3. *Critical issues in UASB reactors.*

Reference	Critical issues	Impacts
Gravity feed from top by tube	Manifold (perforated tube) and lateral	Clogging, hydraulic problems, poor mixing and contact
Upflow velocity: 0,5 – 1,5 m/h	0,13 a 0,47 m/h	Poor expansion sludge blanket, poor performance
HRT: 4 - 10 h	8 – 11,5 h	Treatment volume than is necessary
SLG separator	Improper design	Biomass washed-out, corrosion and odor problems, biogas losses
Perforated submerged outlet	V-notch weirs, Perforated tube poorly constructed	Odor, corrosion and hydraulic problems
Collection and disposal of biogas	Inefficient gas collection	Inadequate performance of the reactor, biogas release in settler
Special devices	Improper drain and sludge sampling valves	Clogging feed tube, hinder sludge evacuation
	Meter and biogas burner out of operation	No record biogas production, release to atmosphere
	Covers in por condition	Biogas release to atmosphere, odor problem

Source: [14,20].

Table 4 shows the critical points identified in the trickling filter and the final settler of the DWWTP. It should be noted that clogging in TF distributor causes a damming of wastewater in the UASB reactor, which exceeds the level of the biogas collection pipe, causing their accumulation and release of the reactor covered by the pressure by biogas.

Table 4. *Critical issues in trickling filter and final settler.*

Unit	Reference	Criticalissues	Impacts
TF	Circular shape	Rectangular	Dry zones, reduced efficiency process
	Rotary distribution	Fixed nozzle distributor	Clogging, inadequate moisture on media, low biomass growth
	Peripheral filter ventilation	Poor ventilation	low biomass grow, odor problems
Final Settler	Circular shape	Rectangular	Dead zones, inadequate solid retention and hydraulic problems
	Sludge purge at least once a day	Weekly, biweekly	Decomposition and flotation of settled solids
	Homogeneous collection	V-notch weirs and perforated plate	Clogging of collection devices, hydraulics problem.

Source: [14,20].

DWWTP Performance

Figure 4 shows that the influent wastewater to the DWWTPs has a typical concentration of a dilute domestic wastewater [42], which is associated with combined sewage systems and that wastewater does not receive industrial contributions or atypical contributions could interfere with biological treatment [43]. The average efficiency COD (65%), BOD_5(90%) and TSS (90%) concentrations of UASB reactors shows that on this unit is transforms most of the organic matter, which coincides with the report by several authors that report reductions between 60-80% and 70-80%, in terms of BOD_5 and TSS, respectively [6,16,24,30].
The observed values when compared with those reported in the literature for UASB reactors followed by aerobic post-treatment indicate good performance of UASB [13,14,20,27,44,45], despite the critical issues identified in both the design and operation, resulting in COD, BOD_5 and TSS concentrations and removal efficiencies in accordance with the reported experiences. Additionally, it emphasizes the considerable TSS removal observed in this unit as a result of the installation of tilted plates in the settling zone, demonstrating the importance of retention of solids in the UASB reactor efficiency.

Moreover, noted that the TF, which acts as a polishing unit, presents a smaller reduction than that achieved in the UASB reactor. However, the concentration and removal efficiency observed in the final effluent is consistent with those reported by literature [17,31,32,46,47].

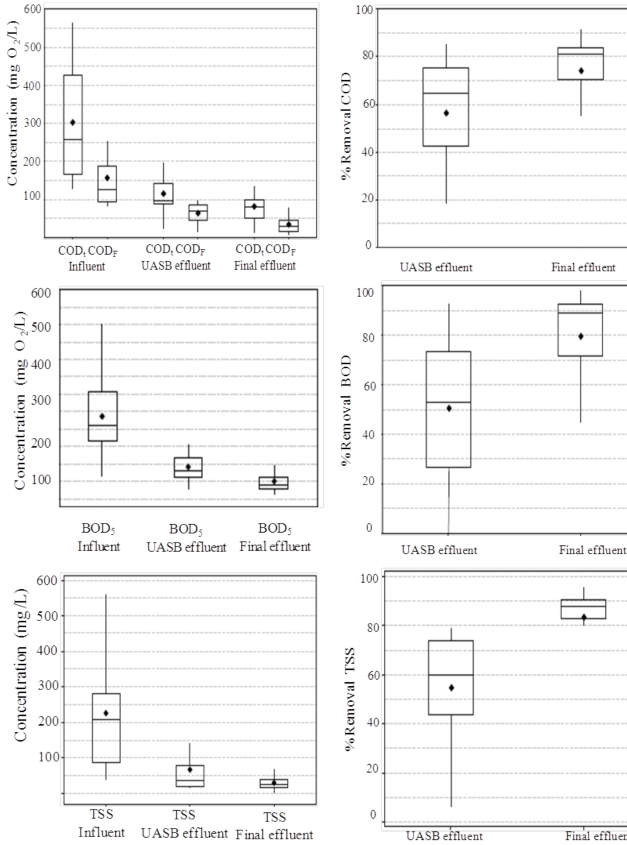

Figure 4. *COD, BOD_5 and TSS Variation.*

Figure 5 shows that the concentrations of TKN and TAN are established within the typical range for domestic wastewater [42,48]. In the UASB effluent, there was a slight decrease in nitrogen and a smaller difference between the two forms of nitrogen, which is associated with ammonification processes. The minimal reduction presented in the final effluent is due that the system was not designed for the nitrogen transformation. However, taking into account that the TF has limitations in design and operation, as well as the final settler, it is possible that optimization strategies permit a further reduction of nitrogen. Table 5 shows a summary of concentration and removal efficiencies for DWWTP as well as reported by research and application.

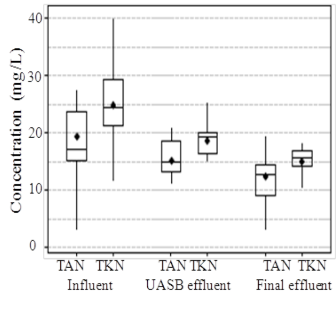

Figure 4. *TKN and TAN's concentration.*

Table 5. *Average concentrations and removal efficiencies in DWWTP evaluated.*

Parameter	Influent	Effluent UASB	Final effluent	
			DWWTP	Reference*
COD (mg/L)	300	120	85	70 - 180
Removal COD (%)	-	60	81	65 - 91
BOD_5 (mg/L)	245	100	50	20 - 60
Removal BOD_5 (%)	-	60	80	75 - 96
TSS (mg/L)	240	60	45	20 - 40
Removal TSS (%)	-	75	81	70 - 93
TKN (mg/L)	25	18	15	> 20
TAN (mg/L)	17	15	13	> 15

Source: [45,49,50]

CONCLUSIONS

Despite the critical issues identified in the design, operation and maintenance, the results show that the UASB/TF configuration achieved COD, BOD_5 and TSS removal efficiencies above 80%. These results demonstrate the effectiveness of technology and the potential of achieving greater efficiencies if they are guaranteed all the recommendations suggested by the literature and practical experience associated with these systems. Such as ensuring mainly an adequate feeding and outlet and SLG separator in UASB reactor and a rotary distribution and adequate ventilation in the TF.
Several advantages of UASB/TF are highlighted, such as operational simplicity, low cost and higher efficiency. These advantages, associated with the favorable environmental conditions in Valle del Cauca, where ambient temperature is above 18ºC have contributed to consider this configuration suitable for the regional context; but more technological knowledge about the design, operation and maintenance will be required to ensure proper performance and to maximize treatment's capacity.

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