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RESEARCH PAPER

Design and implementation of a treatment plant for the disposal of wastewater from portable toilets

Sebastián Núñez, Edison Albert Zuluaga-Hernández, Natalia Teran, Juliana Puello, Laura Ramírez, & Luis Bossa
Universidad de San Buenaventura Cartagena, Grupo de Investigación en Ciencias de la Ingeniería GICI, Engineering Department, Cartagena, Colombia.

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Autor de correspondencia:
Luis Bossa
luis.bossa@usbctg.edu.co

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ABSTRACT

Characterization of wastewater from portable toilets show parameters values (i.e., Chemical Oxygen Demand COD and total suspended solids TSS) that exceed the limits stablished by environmental regulations. This means that a prior treatment of these effluents is mandatory. This paper describes the design and construction of a plant for the treatment of wastewater from portable toilets, in a coastal city with dry/humid tropical weather conditions. The plant has a capacity for the treatment of 2.2 m3 of wastewater every two days. The batch process for the treatment of wastewater from portable toilets consists of primary treatment (screening and sedimentation), secondary treatment (biological activated sludge) and tertiary treatment (disinfection by chlorination, and filtration with activated carbon and gravel filters), in order to eliminate the chemical disintegrator of organic matter, the blue color, bacteria and odors, and to meet the limit values in discharges at surface water bodies and public sewerage system. Cleaner production strategies were also implemented to improve the sustainability of the process, such as the use of recycled material (i.e. the empty containers of agents for organic material disintegration), use of unevennes in the land to decrease energy consumption, use of equipment (tanks and filters) from disused production units and substitution of the toilet disinfectant (which was formaldehyde based disintegrator), for a biodegradable and non-toxic glutaraldehyde-based disinfectant, considering the environmental commitment involved in wastewater treatment processes. The characterization of the treated water from the plant showed that it can be discharged into the sewer. A characterization of the microbia present in the bioreactor is suggested for future research and optimization of the wastewater treatment plant, since the inoculum identified in the process will be a potential adjuvant in other processes for organic material degradation such as septic tanks and wastewater treatment plants located in similar climatic conditions.

Keywords: Bioreactor; Biological treatment; Chemical Oxygen Demand; Pollutants elimination.

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Diseño e implementación de una planta de tratamiento para la disposición de aguas residuales de baños portátiles

RESUMEN

La caracterización de las aguas residuales de los baños portátiles muestran valores de parámetros (i.e. Demanda Química de Oxígeno DQO y sólidos suspendidos totales SST) que superan los límites establecidos por la normativa ambiental. Esto significa que es obligatorio un tratamiento previo de estos efluentes. Este trabajo describe el diseño y construcción de una planta para el tratamiento de aguas residuales de baños portátiles, en una ciudad costera con clima tropical seco/húmedo. La planta tiene una capacidad para el tratamiento de 2,2 m3 de aguas residuales cada dos días. El proceso discontinuo para el tratamiento de aguas residuales de baños portátiles consta de tratamiento primario (cribado y sedimentación), tratamiento secundario (lodos activados biológicos) y tratamiento terciario (desinfección por cloración y filtración con carbón activado y filtros de grava), con el fin de eliminar el desintegrador químico de materia orgánica, el color azul, bacterias y olores, y cumplir los valores límite en vertidos a cuerpos de agua superficiales y alcantarillado público. También se implementaron estrategias de producción más limpia para mejorar la sustentabilidad del proceso, como el uso de material reciclado (es decir, los contenedores vacíos de agentes para la desintegración de materia orgánica), aprovechamiento de desniveles en el terreno para disminuir el consumo de energía, uso de equipos (tanques y filtros) de unidades productivas en desuso y sustitución del desinfectante de inodoro (que era desintegrante a base de formaldehído), por un desinfectante a base de glutaraldehído biodegradable y no tóxico, considerando el compromiso ambiental que implican los procesos de tratamiento de aguas residuales. La caracterización del agua tratada de la planta mostró que puede ser vertida al alcantarillado. Se sugiere una caracterización de los microbios presentes en el biorreactor para futuras investigaciones y optimización de la planta de tratamiento de aguas residuales, ya que el inóculo identificado en el proceso será un adyuvante potencial en otros procesos de degradación de materia orgánica como fosas sépticas y plantas de tratamiento de aguas residuales ubicadas en condiciones climáticas similares.

Palabras clave: Biorreactor; Tratamiento Biológico; Demanda Química de Oxigeno; Eliminación de contaminantes.

1. Introducción

The treatment of non-domestic wastewater is important when it comes to minimizing the impact on the environment caused by the discharge of pollutants into the environment. It consists of a series of physical, chemical and biological processes that aim to eliminate the pollutants that affect both human health and the environment, mainly water reservoirs, lakes, ponds, and natural ponds causing eutrophication, which occurs when water is artificially enriched with nutrients [1]. The quality of the water differs according to the destination or use, which determines the necessary treatment for the wastewater. In this paper, the object of study is the wastewater stored in the septic tanks of portable toilets, which is characterized by high concentrations of pollutants such as microorganisms, floating material (fats and oils), colloidal and dissolved matter (suspended solids, pathogens and other substances), sedimentable material (sands), solid material (plastic, rags or wipers). Inside the septic tanks, a chemical treatment is carried out by means of an organic matter disintegrator whose function is to degrade feces or human waste. Usually, chemical treatments consist of biocides (synthetic or naturally occurring chemicals) such as formaldehyde, glutaraldehyde (commonly used in the disinfection of laboratory and medical equipment) and bronopol, among others. These chemicals carry out the degradation process of organic matter from feces and combat the bacteria that produce bad odors from these residues in the portable toilets [2]. Also, these chemicals are usually blue which works as a visible indicator of the substance and also with the aim of concealing the waste deposited in the tanks. Discharges of wastewater to surface water bodies without treatment bring deterioration of the receiving body and consequently impact on natural resources and communities. Companies that are dedicated to the rental of portable toilets must comply with environmental regulations for discharges in water bodies or sewers [3]. A wastewater treatment plant is a set of physical, chemical or biological unitary systems and operations whose purpose is to eliminate or reduce pollution or undesirable characteristics in wastewater so it has the appropriate environmental characteristics. The combination and nature of the processes in the treatment plant varies depending on both the properties of the wastewater before treatment and its final destination [4]. According to a study carried out by the Quimerk company (portable toilets company), the efficiency of the general system of wastewater treatment plants for this type of water is 90%, obtaining an average final data of COD 47 mg/l, regarding the initial values, which were COD 451 mg/l, thus complying with the wastewater reuse rule [5]. In wastewater treatment plants (WWTP), wastewater treatment plants (WWTP) contemplate three primary phases (removal of solids by settling), secondary (biological decomposition) and tertiary (extra filtration) [6]. The design of a WWTP must guarantee compliance with environmental safety standards so that, during its operation, surrounding communities are not affected, nor is the quality of the air and soil altered [7].

The process carried out is to bring portable baths closer to its customers. Portable baths are used by customers for an average of three days. In this period, the company uses a formaldehyde disintegrator for smell maintenance and control. Then the toilets are collected and taken to the company's facilities in order to collect the waste that is then discharged into the public sewer. In this sense, the A&A company requires implementing the treatment of these waste before being discharged to comply with the current Colombian regulations (Decree 631 of 2015 of the Ministry of Environment). To achieve this, the company acquired some equipment, tanks and pipes from an old wastewater treatment plant from a cement. The objective of this work is to reuse most of the elements acquired by the company, for the implementation of a non -domestic wastewater treatment plant, with which the regulations can be complied with in force in an optimal way.

Portable toilet companies provide a service that consists of bringing portable toilets to the sites required by customers. Portable toilets are used by clients for an average of three days. In this period, companies use a formaldehyde disintegrator for maintenance and odor control. Then the toilets are collected and taken to the facilities of the provider company to collect the waste that is then dumped into the public sewer. In this sense, these companies need to implement a waste treatment before being dumped, to comply with current Colombian regulations (Decree 631 of 2015 of the Ministry of the Environment). The objective of this work consists of the design and construction of a plant for the treatment of wastewater from portable toilets, in Cartagena, Colombia. For this, it was considered to reuse the largest amount of equipment, tanks and pipes from an old wastewater treatment plant from a cement plant, with which current regulations can be optimally met.

2. Experimental

For the location of the plant, the land owned by the company is considered. In this, a space is selected in which there are natural unevenness in the terrain, through which waterfalls can be used. Likewise, adjustments are made to the land in order to stabilize and reduce soil erosion. For the design of the plant, a characterization of the wastewater is initially carried out to determine its physicochemical parameters (content of solids, fats and dissolved salts, percentage of settleable solids, oils, degree of acidity and alkalinity, dissolved oxygen, degree of hardness). and chemical and biological oxygen demand). The amount of coagulant (aluminum sulfate) for solids removal processes is determined from a jar test performed in triplicate. To do this, different amounts of type b aluminum sulfate (10, 15, 20, 40, 60, 70 and 75 g) are added to 1 L of residual water solution, with constant stirring at 200 rpm, in order to have the optimal clotting time. Finally, the P&ID plans, equipment distribution plans and piping calculations are made to carry out the assembly, start-up and evaluation of the plant.

3. Results

3.1 Characterization of wastewater from portable toilets

Table 1 shows the results of the characterization of the wastewater from portable toilets, compared to the limits established by the current regulation. It is observed that BOD, COD, SS, TSS, sulfides, phenol and chlorides reach extremely high values, specifically the COD and BOD5. Additionally, it can be observed that the total suspended solids parameter (TSS) exceeds the established limit of 90 mg/l by 1200%, due to the high concentration of sediments contained in this type of residual water, which accumulates in the tank of the portable toilet. The fats and oil also exceed the permitted limit of 20 mg/l, due to the surfactation caused by the detergent and emulsifying agents present in the chemicals added to the toilet. Sulfides parameter also shows high values (1200 mg/l); sulfides are present due to the metabolizing process of the organic load of wastewater; sulfides cause bad odors, and make it difficult to treat the sludge produced in the WWTP. In future works, hydrogen sulfide bacteria capable of degrading it and eliminating it from the residual sludge must be implemented, making it necessary to analyze the type of bacteria, so it can be used in another process [8].

Table 1: Characterization of wastewater from portable toilets.

Parameter	Units	Method	Result	Limit value**
Fats and oils	mg/l	S.M*. 5520B	92.50	20
Cadmium (total)	mg/l	S.M. 3030-E-311-B	<LD	
Chloride	mg/l	S.M. 4500-C D	4440.00	
Copper (total)	mg/l	S.M. 3030-E-311-B	21.91	
BOD5	mg/l	S.M. 5210-B, 4500-O-G	3800.00	90
COD	mg/l	S.M. 5520-C	4126.00	180
Phenol	mg/l	USEPA 8047	16.86	
Total Petroleum Hydrocarbons TPH	mg/l	S.M. 5520-F	4.00	Analysis and report
Total Mercury	□g/l	S.M. 3112 MOD	<LD	
Total Nickel	□g/l	S.M. 3030-E-311-B	<LD	
pH		S.M. 4500-H-B	8.74	6 a 9
Total Lead	mg/l	S.M. 3030-E-311-B	<LD	
Suspended solids (SS)	mg/l	S.M. 2540-F	53.80	
Total suspended solids (TSS)	mg/l	S.M. 2540-D	1215.00	90
Sulfide	mg/l	S.M. 4500-S2-F	1200.00	
Total Zinc	mg/l	S.M. 3030-E-311-B	0.865	

* S.M. = standard method
** According to the regulation, these are the limit values for non-domestic wastewater, when load is greater than 625 kg/day and less than or equal to 3000 kg/day [3].

It is also observed that the load of metallic pollutants in the wastewater does not represent a danger, which leads to not considering the implementation of tertiary treatments in the wastewater treatment plant. pH value, although it is within the limits specified by the regulation, needs to be adjusted so the sanitizing agent in the chlorination stage is effective. As a cleaner production strategy, the prior formaldehyde-based disinfectant (which was a formaldehyde-based chemical) was substituted for a biodegradable and non-toxic glutaraldehyde-based chemical disinfectant [9].

3.2 Jar test to determine the amount of coagulant

Aluminum sulfate type B (granulated) was used as coagulating agent for the sedimentation stage. Figure 1 shows the results for the jar test. This evidence that, as expected, as the dose of coagulant increases, the coagulation time decreases. In this sense, a dosage of 70 g in 1 L of wastewater allows an efficient removal of suspended solids, which is verified through the measurement of turbidity with values less than 400 NTU, whose value corresponds to the minimum acceptable value for surface natural water bodies in accordance with Decree 1594 of 1987.

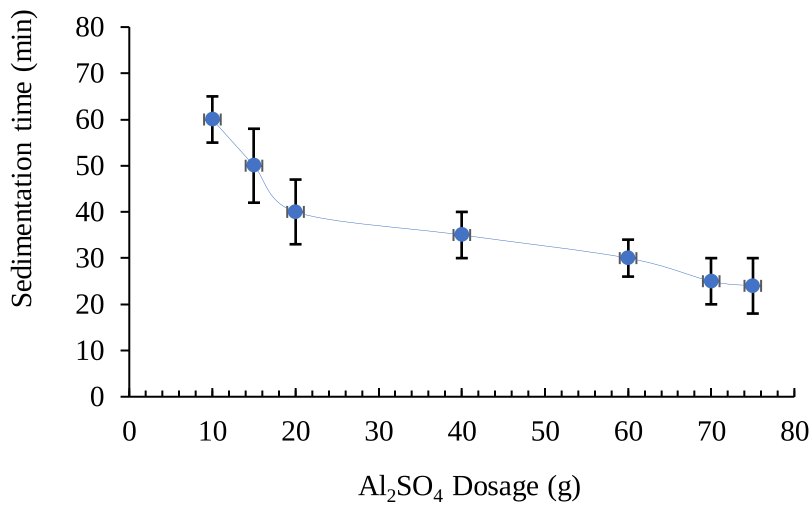

Figure 1. Results of Jar test.

From the results obtained in the jar test, solutions were prepared according to the volume of the coagulation and sedimentation tanks. Although the amount of coagulant added is high compared to other water treatment processes, it should be considered that the effluents handled in this work have a very high solid matter load. On the other hand, although aluminum sulfate tends to lower the pH value, this effect is considered appropriate since urine affects the fermentation stage, so the pH needs to be stabilized below 6.8 for the effectiveness of chlorine.

3.3 Land conditioning

An analysis of both space and terrain was made, seeking that the wastewater treatment plant did not obstruct the traffic of heavy vehicles or interfere with other areas of the company. The available space allows to keep the spacing between tanks and equipment. This land is clayey and has a higher area where the access slope to the upper part is made of concrete and stones. Also, the land is close to a septic tank (located before the construction of the WWTP) and the underground water well that could be used in case of emergency. The slope of the land allowed to carry out a gravity process, which represents an energy saving in the operation of pumps [10]. Based on these characteristics of the terrain, the design of the tanks and pipe sections was carried out. Rubble, garbage, solid waste and dirt were removed, with the help of operators and a backhoe. Then, a layer of asphalt mixture was laid for a resultant available area of 106.59 m2. A control room was built in a 9 m2 area, which houses the control panel for pumps and energy, as well as the storage of chemical inputs to prepare the solutions required in the process.

3.4 Stages of the wastewater treatment operational process

For the design of the operating process of the wastewater treatment plant, the technical regulation of the drinking water and basic sanitation sector (RAS) was considered in each of the stages, since it guides the development of studies and the design of all the components of the water treatment systems, in their stages of conceptualization, design, start-up, operation and maintenance that are developed in Colombia. A general scheme of the process is presented in Figure 2.

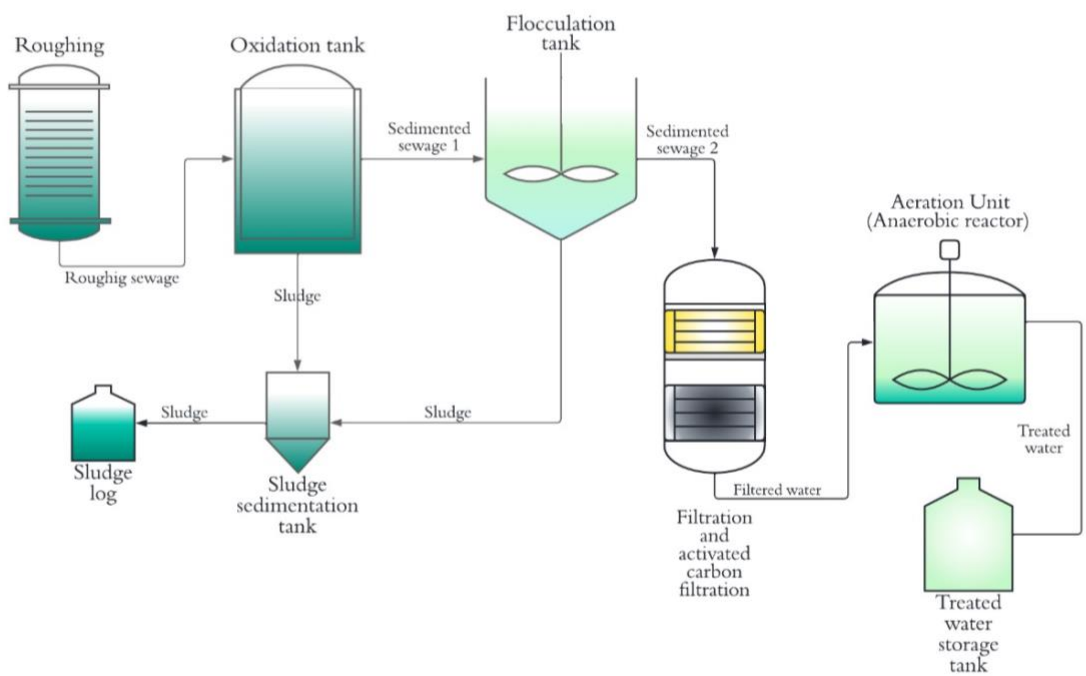

Figure 2. General scheme of the wastewater treatment operational process

Roughing: At this stage, waste such as plastic, rags, wipes and other garbage that people throw down the toilet is collected. For this, three 55-gallon plastic tanks where the glutaraldehyde is shipped were prewashed and reused (figure 3). The tanks were arranged in series and fitted with a stainless-steel collector of 3.5 cm, 1.95 cm and 0.5 cm hole size, respectively, in order to remove the waste, which is later stored in a container. The mentioned process is carried out by gravity. In order to collect the treated water in the roughing, the last tank is connected with a three-inch PVC pipe to the storage tank of the WWTP, which corresponds to a 10 m3 tank made of polyester reinforced with fiberglass (GRP) to store the wastewater to be treated. The storage tank has a 2 HP submersible pump to transport the water to the next process through a 1inch pipe (PVC pressure); It has a 1 in connection (PVC pressure) for the recirculation of sludge coming from the register and a vent that works at the same time as the water level. Additionally, a 1½ inch open gate valve was installed to work by gravity in case of any failure with the submersible pump.

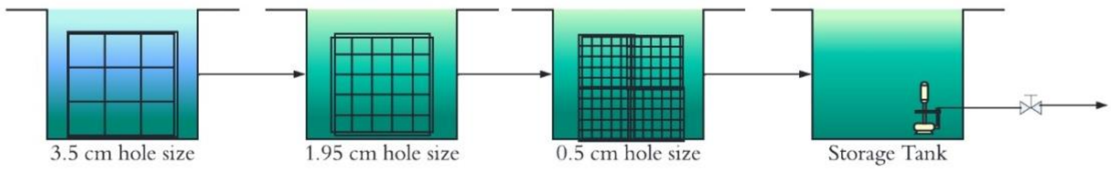

Figure 3. Scheme of roughing process

Oxidation tank: GRP tank with four cavities in which the water with the dosed aluminum sulfate travels one by one and in an upward direction in such a way that short-circuit flow is avoided and the required time of contact is reached. Given that biological and chemical reactions occur in it, sediments that are generated must be evacuated periodically. Each cavity has a 2 in diameter open gate valve outlet connected to the system drain. This system also has in one of its outlets a check system in the main cavity, where the submersible pump is located, connecting it to top of the settling tank, in case that any of the outlet valves is clogged. The total capacity is 3 m3 (diameter: 1.5 m, height: 2 m).

Sludge sedimentation tank: The remaining sludge in the water from the last cavity of the oxidation tank is pumped to the sludge sedimentation tank; due to the load that the water still presents, a dosage of aluminum sulfate solution is added. The sedimentation tank has a truncated cone shape at its base with the vertex downwards to facilitate the concentration of the sludge in the lower part; the excess water is eliminated through butterfly valves arranged at different levels in the conical section of the tank. The excess water is discharged to the sludge register to be chemically treated and recirculated to the storage tank. This sludge sedimentation tank is made of GRP and the base is made of carbon steel. Dimensions: Trunk cone: Height: 0.8 m, bottom diameter: 0.4 m, top diameter: 1.7 m; cylinder: height: 1.8 m, diameter: 1.7 m; outlets diameter: thickened sludge: 3 in pipe, clarified water: four pipes 3 in, 0.2m apart.

Flocculation tank: The remaining sludge in the water of the last cavity of the oxidation tank is pumped to the sludge settling tank, where aluminum sulfate is added to settle the dissolved solids. The sedimentation tank has a frustoconical shape at its base with the vertex downwards to facilitate the concentration of sludge in the lower part; excess water is removed through butterfly valves arranged at different levels in the conical section of the tank. Excess water is discharged to the sludge register to be chemically treated and recirculated to the storage tank. This sludge sedimentation tank is made of GRP and the base is made of carbon steel. Dimensions: Trunk cone: Height: 0.8 m, lower diameter: 0.4 m, upper diameter: 1.7 m; cylinder: height: 1.8 m, diameter: 1.7 m; outlet diameter: thickened sludge: 3-in pipe, clarified water: four 3-in pipes, 0.2 m apart.

Filtration and activated carbon filtration: The water to be filtered leaves the flocculation-sedimentation unit of the sludge blanket and enters the filtration unit, which consists of a cylindrical unit with two cavities: one upflow and one downflow. In the upflow cavity there are gravels and sand stratified from bigger to smaller size in the direction of flow. The filtered water overflows into a circular gutter in the upper part from where it overflows into the descending cavity that has a high molecular adsorption granular activated carbon filter bed to remove impurities dissolved in the water. Then the water runs to the aeration tank, after dosing with sodium hydroxide for pH adjustment. Basic Specifications: diameter: 30 in, height: 2.70 m, construction material: GRP; hydraulic system diameter: 2 in inlet; bottom brace: 2 in, intermediate wash: 1 in, outlet: 2 in.

Aeration unit (anaerobic reactor): The water from the filtration enters by gravity through the middle zone of the anaerobic reactor tank, which is made of GRP and has a capacity of 10 m3. Two processes are carried out in this tank: aeration and disinfection by adding 70% calcium hypochlorite, with a dosage of 4.8 kg per 100 L of water to disinfect 2.5 m3 of residual water. Hypochlorite acts as a scavenger for bacteria that are still in the water. The aeration system of this reactor consists of a 5 HP compressor that feeds air at 40 psi through a 2-inch pipe connected to the reactor tank and then inside the tank through a connection with accessories, a connection of 6 diffusers of fine bubbles 1 m apart each. The fine air bubbles improve the activation and dissolution of the hypochlorite, thereby increasing the temperature inside the tank. Foaming indicates the elimination of bacteria. The action time of the air in this process is approximately 4 hours when the calcium hypochlorite solution is added in the clarification.

Treated water storage tank: This can be considered as a pass-through tank to verify the quality of the water before being discharged to the sewer. It is a 1 m3 capacity tank made of GRP, into which the water from the aeration tank enters through the reactor's submersible pump and a 2-inch pressure PVC pipe. It consists of a discharge pipe in the upper part of the tank that is directed to the sewer system of the company.

Sludge log: The sludge from different stages go to a concrete structure with dimensions 1 m x 1 m x 1 m, where the sludge is separated by chemical treatment with a cationic biopolymer to promote the suspension of the flocs. The sludge cake is approximately 10 cm thick; this is removed and dried in an open and distant place from the personal. The remaining water is recirculated via a 0.5 HP submersible pump to the wastewater storage tank.

3.5 Characterization of the treated water

After the design, construction and commissioning of the non-domestic WWTP, the characterization presented in Table 2 was carried out. The parameters that can be compared with the results before treatment are COD, pH and TSS. It is observed that, in terms of COD, the WWTP has a high efficiency, so the treated water exceeds the requirement to be properly discharged in the sewage.

Table 2. Characterization of the treated wastewater.

Parameters	Units	Method	Result before treatment	Limit value **	Result after treatment
COD	mg/l	S.M.* 5520-C	4126.00	180	32
pH		S.M. 4500-H-B	8.74	6 a 9	7.6
Total suspended solids	mg/l	S.M. 2540-D	1215.00	90	53
O2 (dissolved oxygen)	mg/l	S.M. 4500-O	--	--	6.69
ORP	mV	S.M. 2580	--	--	175.6
Conductivity ms/cm	ms/cm	S.M. 2510	--	--	213

* S.M. = standard method

** According to the regulation, these are the limit values for non-domestic wastewater, when load is greater than 625 kg/day and less than or equal to 3000 kg/day [3].

When analyzing the treated wastewater, parameters such as ORP and dissolved oxygen were taken into account, since these are indicators of the microbiological quality of the water. The ORP value (450 mV) is lower than the potential levels at which bacteria such as E. Coli are killed [11]; therefore, although physicochemical parameters such as TSS and COD are within specifications, it is considered that the treated water represents a potential impact on ecosystems due to the possibility of residual microbial reproduction after treatment, which implies determining the appropriate chlorine dosage for disinfection, so that a suitable ORP results. On the other hand, the result for dissolved oxygen, being greater than 5 mg/l, is appropriate for the conservation of biota in the receiving bodies of treated water, which in this case are estuarine ecosystems due to the coastal location of the city where it is located the WWTP.

4. Conclusions

The quality of the water obtained in WWTP has organoleptic and physicochemical properties within the regulated specifications, in which a 95% reduction in the removal of suspended solids and a removal of 99% of the organic load were reached; these values are acceptable for this type of non-domestic wastewater and allow to categorize the operation of the plant as favorable, so the treated wastewater can be discharged in the sewage network. Even though the ORP is not considered in the regulation, the result shows that bacteria are not completely killed. An analysis for a suitable chlorine treatment is necessary in order to reduce the impact due to the microbiological quality of the wastewater. In general, the results obtained together with the implementation of cleaner production strategies from the conception of the design to the start-up of the plant show the environmental commitment of the company in charge of the treatment of non-domestic wastewater from portable toilets, considering the conservation of coastal ecosystems related to the location of the plant. For future research, it is recommended to identify and characterize the microbiota present in the sludge in order to improve and optimize the stabilization process of these and to be able to take advantage of effective microorganisms in bioprocesses for the degradation of organic matter.

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