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Primary Sewage Sludge Treatment Using A Spiral Support System

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ABSTRACT

Sewage sludge (wastewater treatment solids) is an organic and nutrient resource that is generated during wastewater treatment and is utilized as biosolids in landfills, fertilizer, or compost it requires treatment to reduce the microbial load and the concentration of organic matter and pollutants such as metals. Aerobic digestion has been used for the stabilization of sewage sludge, and the use of biodiscs has been limited to primary sewage rather than sewage sludge. Therefore, this paper shows that the primary sewage sludge from a previously sonicated municipal sewage treatment plant can be stabilized using a spiral support biodisc, which is shown to be an effective mechanism with which to reduce the concentration of pathogenic microorganisms in residual sludge and also reduce the concentration of organic carbon, ammonia-nitrogen (NH_3-N), and soluble phosphorus. The experimental results using the spiral support biodisc are better compared to those using the conventional biodisc.

INTRODUCTION

Two of the main sources of municipal solid waste are organic waste that is produced in homes and the sludge from wastewater treatment (WWT) (Ahmadi-Pirlou et al. 2017). Sewage sludge is considered a by-product that is rich in nutrients like organic matter, phosphorous, and nitrogen (Chuang et al. 2020). Whenever possible the sludge should be returned to nature for environmental and economic reasons (Bartkowska 2014), for which the application of a previous stabilization treatment is generally required to make the sludge suitable for the required purpose. Such treatments yield a product with a lower microbial load which is more suitable for contact with and handling by humans. To determine the degree of stabilization that is achieved when using a given procedure, two stabilization criteria are preferably used: volatile solids content (VSC), reduction of indicator microorganisms, and reduction of pathogenic microorganisms (Mahamud et al. 1996).

The most common sludge stabilization methods are the biological processes of anaerobic digestion and aerobic digestion, but the latter is simpler and requires less capital, hence it has been commonly used in small- and medium-sized wastewater treatment plants (WTPs). Notwithstanding, aerobic digestion requires large digestion tanks, due to the relatively long retention times that are in the range of 15 to 30 days (Song et al. 2010). One method of aerobic digestion that could be effective is the use of the rotating spiral support biodiscs (SSBs).

SSBs or rotating biological contactors (RBCs) consist of a tank that is open to the atmosphere and discs that are coupled by an equidistant axis, and the shafts are constantly rotated, alternately exposing the discs to atmospheric air and the organic matter in the liquid medium. This process facilitates the attachment and growth of microorganisms on the disc surface, thus forming a film of a few millimeters in thickness that covers the entire disc (Von Sperling, 2007). The microorganisms that form the biofilm are responsible for affecting the degradation of the pollutants that are contained in the liquid medium (Qiqi et al. 2012).

The biofilm that forms on the biodiscs carries out biochemical oxygen demand (BOD) removal, and the combined carbon oxidation, nitrification, and denitrification of effluents. As the discs rotate, the bacteria and fungi that constitute the biofilm are alternately exposed to ammonium or nitrite from wastewater and to atmospheric oxygen (Qiqi et al. 2012).

Primary sewage sludge (which is mechanically treated and unstabilized), is not discarded at the original site from which the primary sewage was taken before treatment. This research aimed to stabilize primary sewage sludge using a system of rotating spiral support biodiscs (SSBs) at the laboratory scale.

MATERIALS AND METHODS

Sample Used

Residual sludge from the primary settler of a municipal wastewater treatment plant (WTP) that is located in Ecatepec, State of Mexico, Mexico was used.

Sludge with pH 6.7 that had previously been sonicated and adjusted to pH 5 with four different conditions of frequency and power was studied: 1) 80 kHz with 72 W of power; 2) 80 kHz with 48 W of power; 3) 45 kHz with 80 W of power; 4) 45 kHz and 56 W of power. The following were used as controls: a) non-sonicated mud without pH adjustment; b) non-sonicated mud with adjustment to pH 5 and c) sonicated mud at 45 kHz and 80 W of power without pH adjustment.

Biodisc System

The system that was used in this study consists of a conventional biodisc (CB) and a spiral support biodisc (SSB), and both were located in parallel and operating simultaneously (Fig. 1). The CB and the SSB are made of polyesteramide (PEA) and they are joined longitudinally by a galvanized steel shaft with a length of 45 cm with two bearings and a maintained distance of 8 cm from the base with a capacity of 6.6 L (Fig. 2). The system is housed within a 33 cm long casing that holds the biodisc system at both ends.

For their operation, the CB and the SSB were operated in batch at the laboratory level with a 1 L volume of mud in each of the two systems and the rotation speed was adjusted to 1 rpm. After 15 days of biofilm formation using residual primary sludge, the treatment of this research lasted a total of 7 days.

As response variables to the primary sludge treatment by the CB and the SSB, the following were evaluated: total chemical oxygen demand (COD), total coliforms, fecal coliforms, and total organic carbon (TOC), ammonia-nitrogen (NH_3-N), and soluble phosphorus.

Physicochemical Analysis

Total COD was determined by using the closed reflux method (5220 C), total organic carbon (TOC), ammonia-nitrogen (NH_3-N), soluble phosphorus, and total suspended solids (TSS) according to standardized methods (1995).

Microbiological Analysis

Fecal coliforms and total coliforms were determined by using the most probable number (MPN/ml) technique that was modified from the Official Mexican Norm (NOM-004-SEMARNAT-2002) using sodium lauryl sulfate broth (LSB) for

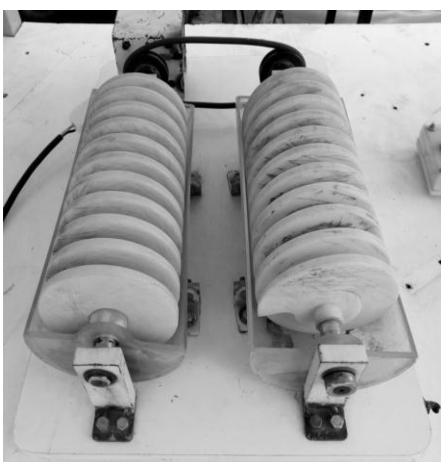

Fig. 1: Conventional biodisc system - CB (left) and spiral biodisc - SSB (right) used for stabilization of primary residual sludge.

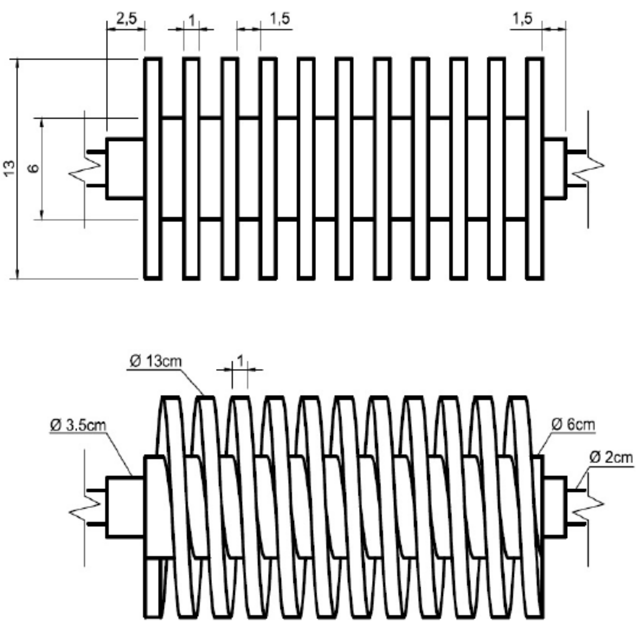

Fig. 2: Conventional biodisc system - CB (top) and spiral biodisc - SSB (bottom) (Reyes-Yañez et al. 2017).

total coliforms and bright green bile broth (BGBB) for fecal coliforms, incubating during 48 h for each test.

Statistical Analysis

As a post hoc test to evaluate the difference between the means of the treatments with a significance level of 0.05, a one-way analysis of variance (ANOVA) and the Tukey test were performed on the obtained results.

RESULTS AND DISCUSSION

Total Coliforms

Both the sonication condition, the type of reactor used, and the interaction of these factors were statistically significant ($P < 0.0001$) regarding the reduction of total coliforms. The treatments applied in the CB concerning the SSB that were statistically different were the control: 45 kHz with 80 W of power without pH adjustment, as well as the treatments with 80 kHz with 48 W of power and 45 kHz with 56 W of power. Greater removals of fecal coliforms were achieved in the sludge that was treated with the SSB, and the control without pH adjustment being sonicated at 45 kHz with 80 W of power was outstanding (Fig. 3), since with this condition 99-100% of total coliforms were removed.

Fecal Coliforms

Of the total fecal coliforms, 99-100% were eliminated in the SSB in 5 of the 7 conditions that were tested (Fig. 4): sonication condition, type of reactor, and interaction between these factors were statistically significant ($P < 0.0001$).

pH 5 treatments without sonicating; 80 kHz with 72 W of power and 45 kHz with 56 W of power had statistically significant differences between them when applied in the CB concerning the SSB. Sonicated sludge treated in the SB removed approximately 60% more fecal coliforms. Tawfik et al. (2004) suggest that the adsorption of the biofilm to the rotating discs could be the mechanism by which the removal of *E. coli* occurs, although the participation of higher organisms or even sedimentation could contribute to the removal of pathogens in the rotary biodiscs.

In this research, higher levels of removal of fecal coliforms were expected in the sludge that was treated on the rotating discs. In previous research in the body of literature, Kulikowska et al. (2010) demonstrated that wastewater treat-

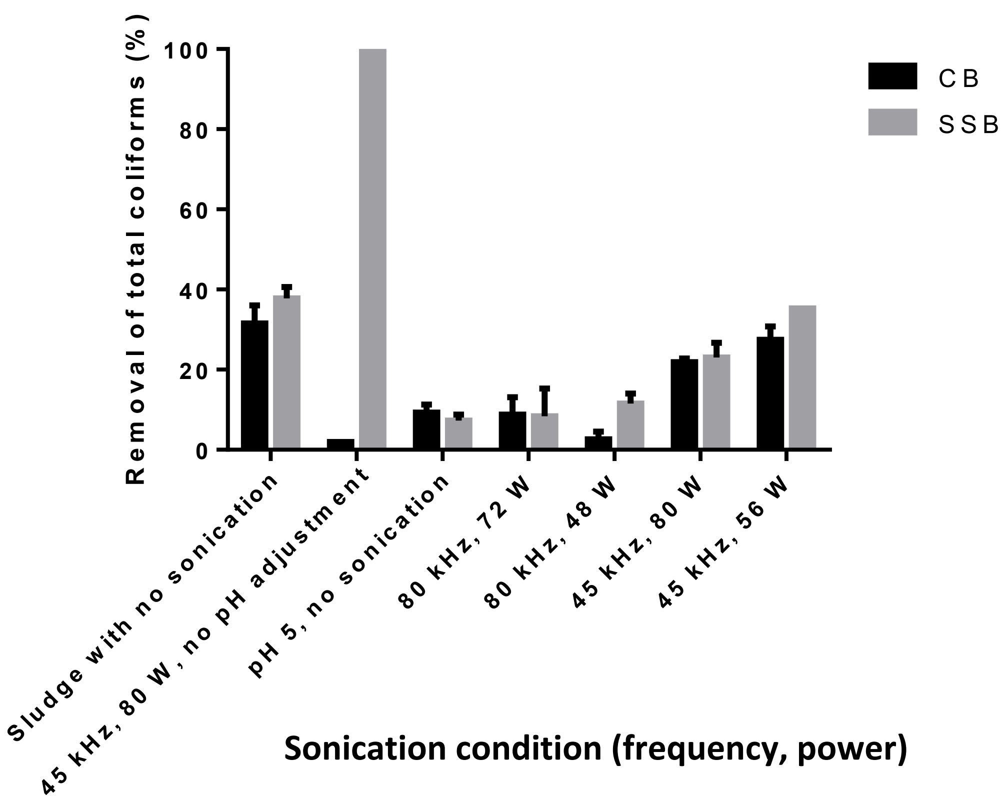

Fig. 3: Removal of total coliforms in the CB and the SSB in sludge pretreated with different sonication conditions.

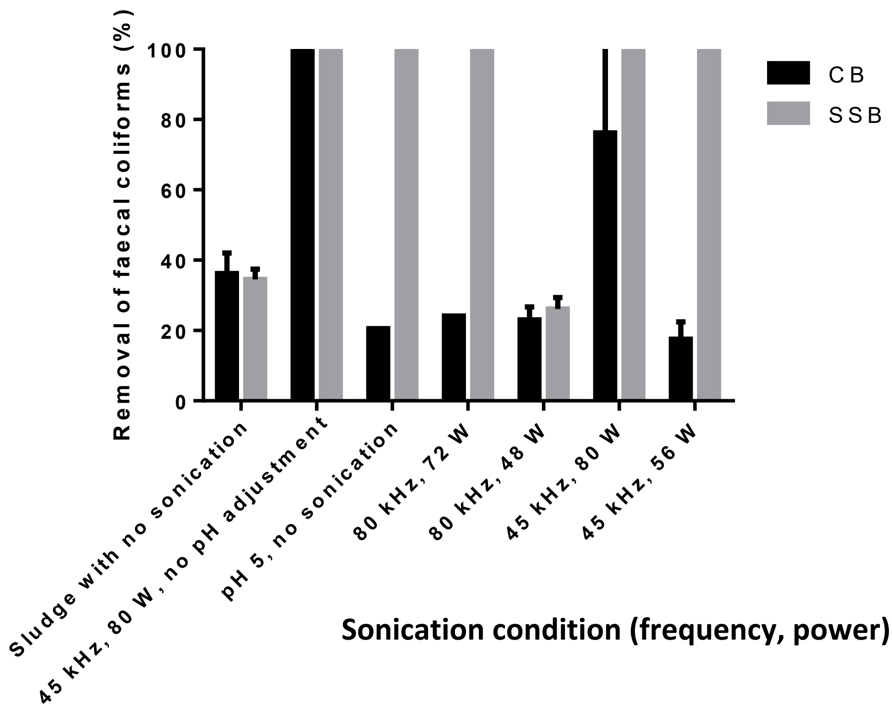

Fig. 4: Removal of fecal coliforms in CB and SSB in sludge pretreated under different sonication conditions.

ment using rotating discs can remove more than 99% of the fecal coliforms in the influent, while Hassard et al. (2014) affirm that rotating disc systems have a fecal coliform removal capacity greater than 90%. These previous results coincide with those obtained in this research with the treatments in the SSB, but not with those of the treatments in the CB, which could be explained by the greater surface area and therefore greater biofilm area of the SSB (Reyes-Yañez 2017).

Carbon and phosphorus were fully consumed in both the CB and the SSB after the 7 days of this experiment, regardless of the sonication conditions that were tested (Table 1). For the control (mud with no sonication and no pH adjustment), both carbon and phosphorus increased in concentration in both reactors. However, ammonia-nitrogen (NH_3-N) had concentration decreases that were greater than 50% with all sonication conditions in the CB,

Table 1: Reduction of carbon, ammonia-nitrogen, and soluble phosphorus in the primary residual sludge after the sonication-aerobic reactor treatment.

				CB Reactor			SSB Reactor		
Treatment	Freq. (kHz)	Power (W)	pH	Reduction in C (%)	Reduction in NH_3-N (%)	Reduction in P (%)	Reduction in C (%)	Reduction in NH_3-N (%)	Reduction in P (%)
1	80	72	5	100±0	89.21± 0.56	100±0	100±0	93.58±0.33	100±0
2	80	48	5	100±0	92.26± 1.77	100±0	100±0	80.29± 1.56	20.08±11.33
3	45	80	5	100±0	53.72± 1.81	100±0	100±0	30.79± 8.99	100±0
4	45	56	5	100±0	62.5± 1.55	100±0	100±0	66.19± 4.41	100±0
5	45	80	6.7	100±0	74.14± 5.81	100±0	100±0	79.34±2.84	Increment 312.5±40.17
6	Control (Mud in its original condition)		6.7	Increment 531.25 ± 54.13	63.42±5.61	Increment 1040.1±461.59	Increment 493.75 ± 132.58	6.04±3.73	Increment
7	Sludge not sonicated		5	100±0	88.71±1.52	100±0	100±0	84.74±2.34	100±0

while in the SSB, NH_3-N had low levels of removal for the sonicated mud at 45 kHz and 80 W of power, as well as for the non-sonicated mud (Table 1). These results coincide with those of the research by Pynaert et al. (2003), who note that biodisc treatment systems tend to produce effluents that are rich in NH_3-N and poor in biodegradable organic carbon (BOC), finding the removal of 89 ± 5% of the influent nitrogen, with N_2 as the main final product in synthetic wastewater (SWW), when using a laboratory-scale rotating biological contactor (RBC; biological fixed-film treatment process).

Taking into account the final amount of fecal coliforms that were present in the sludge after applying the different sonication conditions and the subsequent treatment in the aerobic reactor, both in the CB and the SSB, the sludge was considered to be stabilized (Table 2), since it complied with the maximum permissible limits that have been established in the Official Mexican Norm (NOM-004-SEMARNAT-2002) and, therefore, can be used as biosolids in categories of Class A, Class B, or Class C (Table 3), hence it can be asserted that the treatments in both reactors are effective in reducing the number of fecal coliforms. It is noteworthy that from the beginning of this experiment, there was no presence of Salmonella spp. or helminth eggs (ova) in the primary sludge, hence the treatment was evaluated by only considering the fecal coliforms.

When considering the results that were obtained from the treatment in the reactors (Table 2), all of the sludge that was treated in the CB and the SSB was considered to be Excellent biosolids or Good biosolids, in accordance with the provisions of NOM-004-SEMARNAT-2002 and they are applicable for forestry, agricultural, and soil improvement uses (Table 4). Additionally, Class A sludge can also be used in an urban setting with direct public contact. Therefore, adding biosolids to soil could contribute to increasing the quality of crops because of nitrogen and phosphorous concentration (Balaganesh et al. 2020).

Table 2: Fecal coliforms present in post-treatment treatments in CB and SSB.

	Conventional biodisc			**Spiral support biodisc**		
Treatment	Fecal coliforms (MPN.g^{-1})	Stabilized?	Class	Fecal coliforms (MPN.g^{-1})	Stabilized?	Class
Control (Mud with no sonication, in its original condition)	188 000	Yes	C	184 000	Yes	C
45 kHz, 80 W, no pH adjustment	0	Yes	A	0	Yes	A
pH 5, no sonication	30 000	Yes	C	0	Yes	A
80 kHz, 72 W, pH 5	36 000	Yes	C	0	Yes	A
80 kHz, 48 W, pH 5	72 700	Yes	C	46 300	Yes	C
45 kHz, 80 W, pH 5	10 000	Yes	C	0	Yes	A
45 kHz, 56 W, pH 5	60 700	Yes	C	0	Yes	A

Table 3: Maximum permissible limits for pathogens and parasites in sludge and biosolids established in the Mexican Norm NOM-004-SEMARNAT-2002.

Class	Fecal coliforms MPN.g^{-1} on a dry basis	*Salmonella spp.* MPN.g^{-1} on a dry basis	Helminth eggs /g on a dry basis
A	< 1 000	< 3	< 1
B	< 1 000	< 3	< 10
C	< 2 000 000	< 300	< 35

Table 4: Use of solids according to the type and class established in the Mexican Norm NOM-004-SEMARNAT-2002.

Type	Class	Exploitation
Excellent	A	Urban use WITH direct public contact during its application Those established for Class B and Class C
Excellent or Good	B	Urban use with NO direct public contact during its application Those established for Class C
Excellent or Good	C	Forestal use Soil improvement Agricultural use

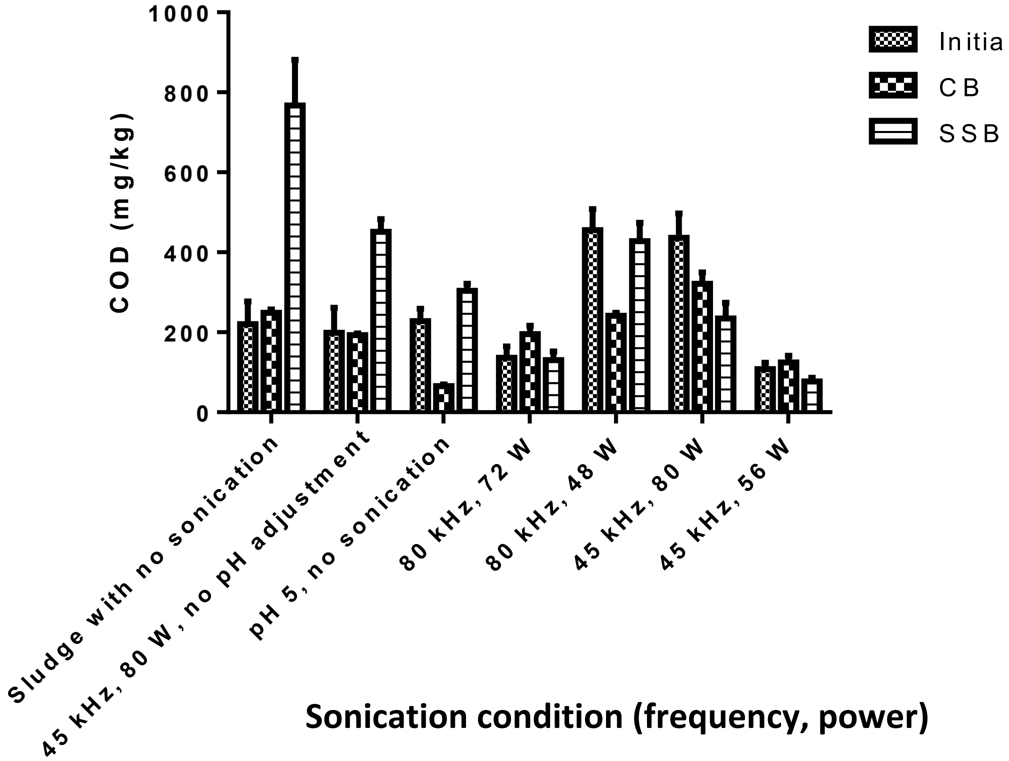

Fig. 5: Variation of COD in pretreated sludge with different sonication conditions in the CB and the SSB.

COD

After sonicating the residual sludge under different conditions, and its subsequent treatment in the CB and the SSB, an increase in total chemical oxygen demand (COD) was observed in some cases, mainly in the SSB, while in the treatments in the CB a decrease in COD was observed (Fig. 5). The COD is an indirect parameter for measuring organic matter, hence the increase in this could represent the dispersion of aggregates that are present in the residual sludge or it could even be explained by the detachment of the biofilm from the discs or the spiral, with the biofilm remaining in the liquid phase and adding to the treatment process (Husham et al. 2012).

However, the decrease in COD could be due to the aerobic oxidation of organic matter at was carried out in the biodisc system, where many events occur simultaneously, including the transport of substrate and oxygen from the sludge to the biofilm microorganisms (Andreadakis et al. 1993).

Although the SSB treatments had greater levels of removal of fecal coliforms (Fig. 4), the opposite behavior was observed in the COD determinations (Fig. 5). These treatments are in contrast with what was reported by Reyes-Yañez et al. (2017), who noted 82% removal of COD from wastewater treated for 180 h in their spiral reactor, against 74% removal of COD that was achieved by treatment in their disc reactor. In the present study, the differences that were found between the CB and the SSB could be due to the concentration of microorganisms, since the CB has a greater specific area and, therefore, a greater number of microorganisms. Another aspect could be the difference in the distribution of organic matter, nutrients, and aeration, which are facilitated by the movement which is generated by the spiral biodisc compared to the conventional biodisc (Reyes-Yañez et al. 2017).

It is noteworthy that after the treatment of the sludge in the CB and the SSB, the elimination of the characteristic bad odor (i.e., Hydrogen sulfide, H_2S) of the mud was perceived, in addition to changes in the color of the mud, starting with dark brown and ending with light brown. This fact is explained by the concentration of organic matter that is present, with a darker color concerning the higher concentration of organic matter, as confirmed by Andreadakis et al. (1993) in their research when testing a biodisc at the laboratory level. Furthermore, the suspended solids (sediments) concentration (SSC) decreased by more than 95% in all of the conditions that were tested (Fig. 6). This result agrees with the result in

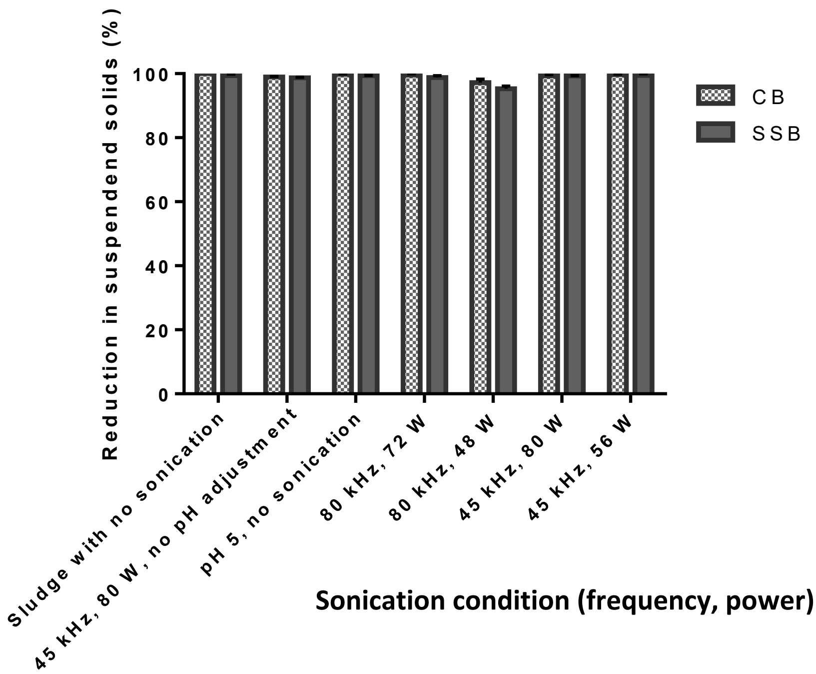

Fig. 6: Reduction of suspended solids in the mud after treatment with sonication and biodiscs - CB + SSB.

the research of Tawfik et al. (2004), where those authors note that most of the *E. coli* population was found in suspended solids, which would explain the decrease in fecal coliforms in the systems treated in both the CB and the SSB in the present study.

CONCLUSION

After treating the primary sewage with the sequence of sonication-CB and sonication-SSB, in some cases, there was an increase in the concentration of organic matter that was measured as COD observed, while in some other cases, the concentration of organic matter decreased. In the primary sludge that was treated with the CB, the concentrations of total coliforms and fecal coliforms decreased, although the SSB eliminated fecal coliforms in most of the conditions that were tested. Notwithstanding, the sludge resulting from the treatment of both systems is considered to be made up of biosolids because they constitute a stabilized sludge following treatment, hence according to the Official Mexican Norm (NOM-004-SEMARNAT-2002) this can be used for urban, agricultural, soil improvement, and forestry uses. It is necessary to evaluate the treatment time of the sludge using the biodisc systems to determine the minimum time reached, in accordance with the parameters established in NOM-004-SEMARNAT-2002 regarding its proper use.

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