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EFFICIENCY OF AN UPFLOW ANAEROBIC FILTER FOR POULTRY EFFLUENT TREATMENT

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ABSTRACT

Poultry slaughterhouses discharge large quantities of effluents that can be treated biologically. The objective of this study was to evaluate the chemical oxygen demand (COD) removal efficiency of an upflow anaerobic filter (UAF) with effluents from a poultry slaughterhouse, using volcanic stone (tezontle) as a support medium. Effluent characterization was carried out in accordance with Mexican official standards and standard methods. The support medium was inoculated with activated sludge from an urban wastewater treatment plant. The filter was operated in continuous flow with applied volumetric loads (AVL) of 1, 1.5, 2, 2.5, and 3 kg COD m^{-3} d^{-1} and hydraulic retention times (HRT) of 5.8, 3.8, 2.9, 2.3, and 1.9 days. An analysis of variance (ANOVA) was performed, and significant differences were determined for each AVL using the Krustall-Wallis method. The results obtained in the gradually applied AVL were 26.1, 53.2, 40.1, 17, and 49.7 % COD removal. However, in the AVL of 2 and 2.5 kg COD m^{-3} d^{-1}, there was a decrease in the removal, which is attributed to the destabilization of the system due to the increase in loads. The maximum methane production was 125 mL at an AVL of 3 kg COD m^{-3} d^{-1}, with a methane yield (YCH_4) of 0.082 L_{CH4} g^{-1} COD^{-1}_{rem}. With no increase in methane production at each AVL, the theoretical yield of 0.328 L_{CH4} g^{-1} COD^{-1}_{rem}. was not met. The upflow anaerobic filter demonstrated its efficiency with a poultry effluent, with maximum COD removal greater than 50 %; however, more acclimatization time is required for the formation of biofilm in the support medium, a pretreatment that removes the high organic load and allows for gradual biogas production.

Keywords: chemical oxygen demand, methane production, acclimatization.

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INTRODUCTION

Poultry meat accounted for about 35 % of world meat production in 2019, being the most produced type of meat in absolute and relative terms since 2000 (59 million Mg) (FAO, 2021). In Mexico, poultry farming is the most dynamic livestock activity in terms of production volume and consumption (CEDRSSA, 2018). Chicken meat is the most consumed protein in the country; six out of ten people include eggs and chicken in their daily diet, since both products are within the economic reach of Mexican families, with high nutritional content, accessibility, and versatility (UNA, 2021). This meat is produced with the advantage of a short fattening period, with the bird being marketed at seven weeks of age, weighing approximately 0.8–1 kg. Therefore, on a large scale, poultry farming is one of the most profitable economic activities (Castañeda, 2018).

Poultry slaughterhouses and processing generate different wastes and highly perishable organic by-products. Waste management can be aimed at obtaining new products with added value as agricultural fertilizers (Nieto *et al*., 2022). Researchers suggest that anaerobic digestion is the most suitable treatment for the management of these effluents and the generation of biogas as an energy source (Buenrostro *et al*., 2000). Among its benefits is the reduction of nuisance odors, as well as the ability to conserve nutrients that do not contain carbon in the digested material, which can be recovered for use as fertilizers or, eventually, in animal feed (FAO, 2013).

There are several technologies for the anaerobic treatment of poultry effluents, which can be divided into two main categories depending on the organic loading rate: low-rate (lagoons) and high-rate systems (López-López and Vallejo-Rodríguez, 2019). Anaerobic filters are considered useful systems, due to the high organic loading rates they tolerate for the treatment of low- and high-concentration effluents (Rajakumar *et al.,* 2011). These filters are characterized by having a layer of support material (bed) inside, on which microorganisms are fixed, forming biofilms (Fia *et al*., 2012).

The objective of this work was to evaluate the COD removal efficiency of an upflow anaerobic filter in continuous mode for the treatment of poultry effluents, using volcanic stone (tezontle) as a support medium.

MATERIALS AND METHODS

Anaerobic Upflow Filter

A laboratory-scale upflow anaerobic filter (UAF) made of acrylic was used, with the following dimensions: 50 cm high, 9.5 cm in diameter, and a useful volume of 2.4 L (Figure 1). Along the column, there are two ports, one for recirculation and the other for effluent outlet and sampling.

The filter had an upflow poultry effluent feeding and recirculation system using a Cole-Parmer Masterflex pump and a peristaltic pump (Masterflex Easy Load II, Germany); recirculation was carried out at an upward speed of 0.2 to 0.8 mL min^{-1}, respectively. The hydrodynamic conditions applied allowed the proliferation of microorganisms and their adhesion to the support medium to form a biofilm.

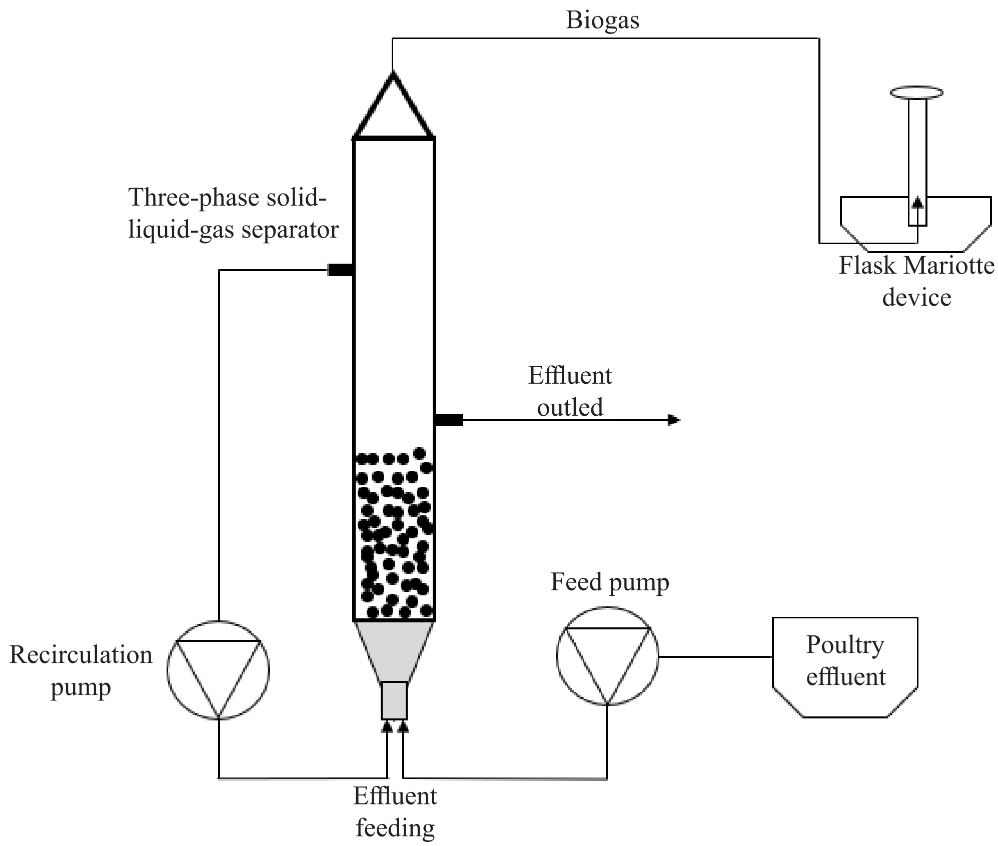

Figure 1. Diagram of the upflow anaerobic filter (UAF). Feed pump, recirculation pump, three-phase solid-liquid-gas separator, and a Flask Mariotte device.

The biogas outlet moved through the top of the reactor through a three-phase solid-gas-liquid separator with a hose connected to the Mariotte Flask-type volumetric device. The device contained 3N sodium hydroxide (NaOH) for the separation of the methane contained in the biogas produced by the reactor.

Characterization of the poultry effluent

Eighty liters of effluent were collected from a poultry slaughterhouse located in the city of Huatusco, Veracruz, Mexico (19° 8′ 58.35″ N, 96° 57′ 51.29″ W, at an altitude of 1300 m). The temperature and pH of the effluent were recorded. Samples were preserved in refrigeration at 4 °C and transported to the Aquatic Resources Research Laboratory (LIRA) of the Boca del Río Technological Institute (ITBoca) for analysis and use in the experimental stage.

Effluent characterization was performed based on the techniques established in the Mexican official standard NOM-001-SEMARNAT-2021 (DOF, 2021) and the standardized methods for water and wastewater analysis (Baird and Bridgewater, 2017). The following parameters were evaluated: pH, temperature, total solids (TS), total volatile solids (TVS), total suspended solids (TSS), volatile suspended solids (VSS), settleable solids (SS), chemical oxygen demand (COD), and total phosphorus (TP).

Biomass acclimatization

To acclimatize the biomass, the support medium (volcanic rock, tezontle) was inoculated with activated sludge from an urban wastewater treatment plant, with a concentration of 2930 mg VSS L^{-1} (Figure 2).

Figure 2. Support medium (tezontle) used. A: uninoculated; B: Inoculated (biofilm formation).

The support medium was selected for its high porosity (>65 %), grain size approximately 20–25 mm, bulk density (1.16 g cm^{-3}), surface area at volume ratio (390 m^2 m^{-3}) (Merino-Solis *et al*., 2015), particle size (20 to 25 mm), and high surface/volume ratio (390 m^2 m^{-3}). Tezontle has been tested and used in several environmental applications as a filter medium in wetlands and pilot-scale treatment plants (López-López *et al*., 2010). To favor inoculum performance, an inorganic medium solution (Kawahara *et al*., 1999) was added to provide nutrients and pH control. The acclimatization time was 14 days, after which the filter began to operate, occupying 50 % of the useful volume of the reactor.

Start-up and continuous operation

The following operating variables were determined: applied volumetric load (AVL), feed flow (Q), hydraulic retention time (HRT), recirculation flow (Q_R), ascensional velocity (Vasc), and percentage of support medium. The effluent was filtered and screened before entering the reactor according to Dlamini *et al*. (2021), due to its high concentration of solids such as feathers, bones, and skin pieces. The reactor operation was carried out in triplicate in each AVL to stabilize the system and was monitored daily to analyze its evolution. To start the continuous flow operation (Figure 3), volumetric loads were gradually applied from an AVL of 1 to 3 kg COD m^{-3} d^{-1}.

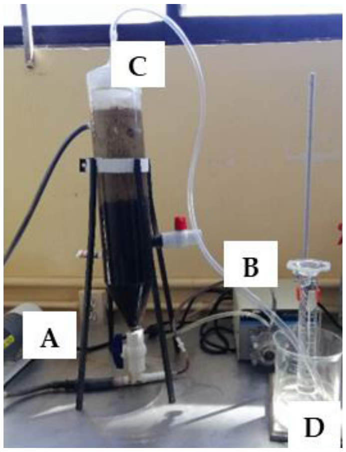

Figure 3. Continuous flow operation of the Upflow Anaerobic Filter (UAF). A: feed pump, B: recirculation pump; C: three-phase solid-liquid-gas separator; D: Mariotte Flask Device.

The hydraulic retention times (HRT) applied were 5.83 d, decreasing to 1.94 d. The operating conditions of the UAF (Table 1) were established by the COD. Njoya *et al*. (2019) indicate that to avoid overloading the pellet-based system, operation is initially performed at an AVL ranging from 1.1 to 4.5 kg COD m^{-3} d^{-1}.

Table 1. Operating conditions of the upflow anaerobic filter (UAF).

Applied volumetric load (kg COD m^{-3} d^{-1})	Feed flow (L d^{-1})	Hydraulic retention time (d)
1	0.412	5.83
1.5	0.618	3.88
2	0.824	2.91
2.5	1.030	2.33
3	1.236	1.94

Statistical analysis

An analysis of variance (ANOVA) was performed using Minitab 18 Statistical Software to determine the mean, standard deviation, maximums, and minimums of the organic matter removal efficiencies. The Krustall-Wallis method was applied to determine the significant differences of each AVL with their respective replicates.

RESULTS AND DISCUSSION

Characterization of poultry wastewater

From the results of the physicochemical characterization of the poultry effluent (Table 2), the average pH value was 6.5 and the effluent temperature was 38.5 °C. These values are in a similar range to those reported by Caldera *et al*. (2010), who characterized effluents from the poultry industry with results of 6.3 pH and 30 °C temperature.

Table 2. Characterization of poultry effluent.

Parameter	Concentration (mg L^{-1})
pH	6.5
Temperature (°C)	38.5
COD	5825
Phosphorus	23.4
TS	2655
TVS	1565
TSS	1250
VSS	1340

The COD concentration was 5825 mg L^{-1}, which is similar to the findings of Cáceres-Escorcia and Romero-Rojas (2018), who analyzed effluents from a poultry slaughterhouse and obtained a COD of 6750 mg L^{-1}. Also, Njoya *et al*. (2020) present a value of 5354.5 mg L^{-1} of poultry effluent COD. Yousefi *et al*. (2018) measured phosphorus content in poultry wastewater and found values ranging from 23 to 129 mg L^{-1}, compared to this study's value of 23.4 mg L^{-1}. On the other hand, Massé and Massé (2000) reported that meat processing generates large volumes of effluents and a significant amount of organic matter measured as COD in the range of 5000–20 000 mg L^{-1}, in addition to having high concentrations of nutrients and pathogenic microorganisms. Aranda-Caraballo (2018) mentions in his study that the presence of blood contributes a higher proportion of contaminants to the total organic load of the waste.

Another parameter characterized in this project was TSS, with a concentration of 1250 mg L^{-1}, which was lower than that recorded by Yaakob *et al*. (2018), who reported an average concentration of 3438 mg L^{-1}. The study was conducted at a location in Malaysia to determine the adverse effects on the environment and natural water systems. The TSS values are low when compared to those of other authors, but Bazrafshan *et al*. (2012) indicate that TSS derived from poultry effluent comes from the cleaning of chicken stomach, intestinal mucus, undigested feed, blood, feathers, and loose meat.

Evolution of chemical oxygen demand (COD) removal efficiency

The continuous flow operation in the UAF started with an AVL of 1 kg COD m^{-3} d^{-1}, HRT of 5.83 days and 16 days of operation; the maximum removal value was 46.4 % (1612 mg COD L^{-1}), with an average of 26.1 % and a minimum value of 8.3 % (2758 mg COD L^{-1}) (Figure 4). Basitere *et al*. (2016) used an expanded granular sludge bed (EGSB) with poultry effluent from a slaughterhouse. The COD characterization resulted in values from 2133 to 4137 mg L^{-1} for the effluent analyzed in the present work. An AVL of 0.5, 0.7, and 1 kg COD m^{-3} d^{-1} was used, obtaining average percentages of 40, 57, and 55 %, respectively.

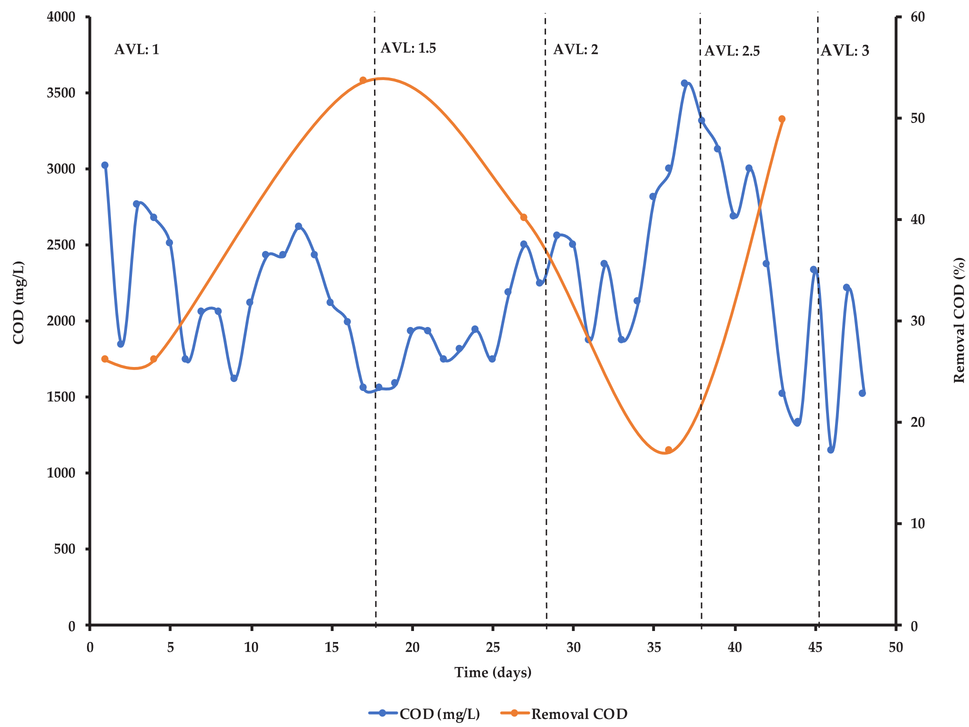

Figure 4. Evolution of the chemical oxygen demand (COD) removal in continuous mode.

Basitere *et al*. (2017) state that COD removal during the first weeks of operation fluctuates due to the acclimatization of the microbial culture to the effluent being used. In a study conducted by Yousefi *et al*. (2018), two high-loading reactors were used, as well as an anaerobic filter with corrugated pvc tubes as support media and an anaerobic baffle reactor. The substrate used was poultry slaughterhouse wastewater, and an AVL of 1 kg COD m^{-3} d^{-1} was applied, resulting in COD removals of 68.83, 78.46, and 79.39 % for HRTs of 18, 24, and 36 hrs.

When an AVL of 1.5 kg COD m^{-3} d^{-1} was applied in the UAF, a maximum removal rate of 59.8 % (1550 mg COD L^{-1}), an average of 53.5 %, and a minimum of 43.5 % (2181 mg COD L^{-1}) were obtained. A study by del Nery *et al*. (2007) evaluated the treatment of poultry effluents with an upflow anaerobic reactor (UASB), reaching efficiencies of 67 % COD removal at an AVL of 1.6 ± 0.4 kg COD m^{-3} d^{-1}. Although the similarity of AVL in both studies shows removal greater than 50 %, the technologies used are different; in a UASB reactor, high loads can be applied, while a filter (UAF) depends on the formation of biofilm to obtain higher efficiencies in the removal of organic matter.
The COD removal at an AVL of 2 kg COD m^{-3} d^{-1} reached maximum and minimum values of 51.6 % (1868 mg COD L^{-1}) and 27.3 % (2806 mg COD L^{-1}), respectively (Table 3). Basitere *et al.* (2017) operated a system of a fixed granular bed reactor coupled with a laboratory-scale ultrafiltration membrane system to treat poultry slaughterhouse effluents, with an average concentration of 2903 mg COD L^{-1}, applying organic loads from 0.5 to 3.1 kg COD m^{-3} d^{-1}, with HRT of 55 h during 64 days, reaching 93 % removal during the first week of operation. However, COD removal fluctuated between days 50 and 64, when the HRT was reduced to 40 h and the load increased to 3.1 kg COD m^{-3} d^{-1}. The authors point out that this decrease in removal during this period can be attributed to the destabilization of the system following the increase in organic load, as well as to the backwashing process.

Table 3. Average values of COD removal efficiency per load.

Applied volumetric loads (kg COD m^{-3} d^{-1})	Hydraulic retention time (days)	Removal (%)
1	5.83	26.1
1.5	3.88	53.2
2	2.91	40.1
2.5	2.33	17
3	1.94	49.7

From the AVL using 2.5 kg COD m^{-3} d^{-1}, the behavior was variable (Table 3), presenting a maximum value of 30.9 % (2368 mg COD L^{-1}), an average of 17 %, and a minimum of 7.9 % (3556 mg COD L^{-1}). This decrease in removal can be attributed to the accumulation of fats and oils on the surface of the filter bed, in relation to what is argued by López-López *et al*. (2010), who postulate that the anaerobic biotransformation of fats and oils generates volatile fatty acids and inhibits anaerobic processes. Borja *et al*. (1998) examined the performance of a hybrid anaerobic reactor that combined an upflow anaerobic sludge blanket reactor with an anaerobic filter, using polyurethane as a support medium with a combination of effluents (70 % bovine effluent and 30 % swine effluent). An AVL of 2.4 kg COD m^{-3} d^{-1} was evaluated, and 90.2 % removal was obtained with a COD of 3740 mg L^{-1}, at a temperature of 35 °C.

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Using an AVL of 3 kg COD m^{-3} d^{-1} resulted in high removal percentages (Table 3), with a maximum value of 65.6 % (1143 mg COD L^{-1}), an average of 49 %, and a minimum of 30 % (2331 mg COD L^{-1}). In addition, Massé and Massé (2000) mention that loads higher than 3 kg COD m^{-3} d^{-1} present good conditions for biomass retention. This is demonstrated by the anaerobic treatment applied to poultry effluents, which ranged between 6908 and 11 500 mg L^{-1}, with removal efficiencies of 90 and 96 % and loads of 2.07 and 4.93 kg COD m^{-3} d^{-1}, operating at a temperature of 30 °C.
COD removals increase with increasing AVL, as reported by Yousefi *et al*. (2018), who applied organic loads of 4, 7, and 10 kg COD m^{-3} d^{-1}, and with COD removals greater than 85 %. There is a statistically significant difference between the experiments (Figure 5). The AVL of 2.5 kg COD m^{-3} d^{-1} differs significantly from the other experiments. According to the Krustall-Wallis test, based on the criterion to accept or reject the hypothesis with a significance level of 0.05, the null hypothesis is rejected, indicating that all the means of the experiments are equal.

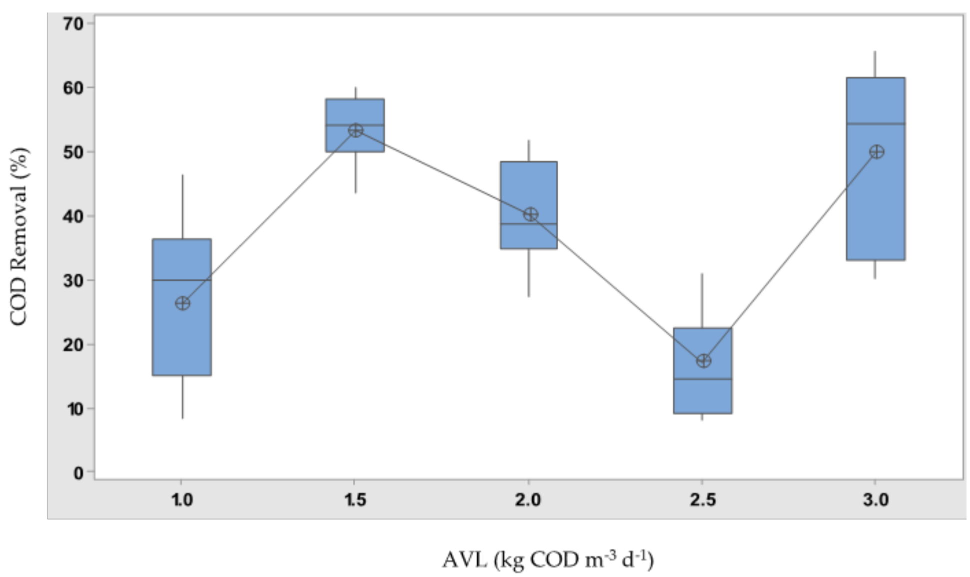

Figure 5. Significance ratio of the chemical oxygen demand (COD) per applied volumetric load (AVL).

The theoretical value of methane yield is considered to be 0.35 L_{CH4} g^{-1} COD^{-1}_{rem} under 0 °C conditions (Michaud *et al*., 2002). In this study, the average temperature was 25 °C and the theoretical yield was 0.328 L_{CH4} g^{-1} $COD^{-}_{1rem.}$ During the first week of operation, CH_4 production was minimal, to the extent that there was no displacement in the Flask Mariotte device. This can be attributed to bacterial growth in its latency and acclimatization stage; this assertion was based on different studies, such as Madigan *et al*. (2003), which indicate that the energy input provided by the proton motive force is directed to anabolic activity.

Michaud *et al*. (2002) mention that during the start-up of a biofilm system, bacteria use carbon to build the initial biopolymer matrix, which reduces methane yield. Like Corrales *et al*. (2015), they highlight that methanogenic bacteria are considered the most important within the consortium of anaerobic microorganisms since they produce methane (CH_4) through the conversion of monocarbon substrates or substrates with carbon atoms joined by a covalent bond.

During continuous mode filter operation, a maximum value of 0.084 L_{CH4} g^{-1} COD^{-1}_{rem} was reported for the AVL of 3 kg COD m^{-3} d^{-1}, and a minimum of 0.0004 L_{CH4} g^{-1} COD^{-1}_{rem} was reported for the AVL of 1 kg COD m^{-3} d^{-1} (Figure 6).

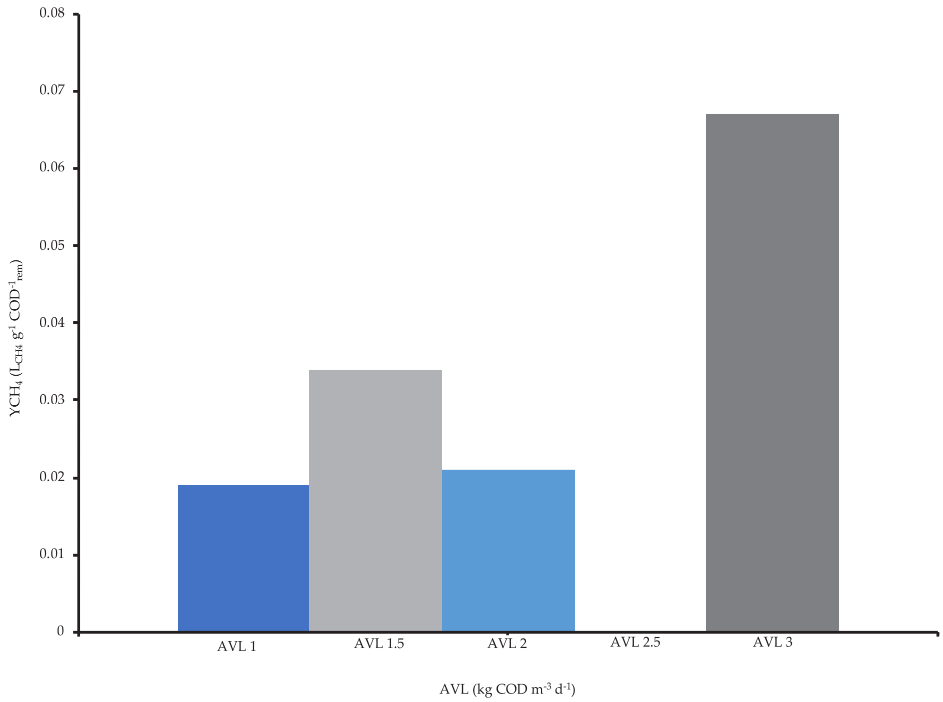

Figure 6. Methane (YCH_4) yield in terms of time.

The YCH_4 values obtained are not close to the theoretical value of 0.328 L_{CH4} g^{-1} COD^{-1}_{rem}. Results close to this theoretical yield should have been presented, such as those by Borja *et al*. (1998), who recorded methane yields of 0.349 and 0.331 L_{CH4} g^{-1} COD^{-1}_{rem} at an AVL of 2.49 and 3.43 kg COD m^{-3} d^{-1}, respectively, during the treatment of poultry effluents in a laboratory-scale anaerobic reactor. However Dlamini *et al*. (2021) treated poultry wastewater in a laboratory-scale plant with a biological pretreatment coupled to an expanded granular bed reactor with downflow, and reported methane gas production in the start-up period of 0.3 L_{CH4} g^{-1}, which was attributed to the application of a novel bioremediation agent called Eco-flush™, which allowed the removal of 39 % COD.

CONCLUSIONS

Effluents from poultry slaughterhouses contain high concentrations of chemical oxygen demand (COD) as well as a large quantity of solids, exceeding the maximum permissible limits set by NOM-001-SEMARNAT-2021 (DOF, 2021). This characterization allows the application of biological treatment to reduce chemical oxygen demand, proteins, fats, and organic matter present in the effluent.

The highest removal efficiency obtained was 53 %, when applying an applied volumetric load (AVL) of 1.5 kg COD m^{-3} d^{-1} with this type of filter in the treatment of poultry effluents. Methane production was obtained with a maximum value of 125 mL at an AVL of 3 kg COD m^{-3} d^{-1}, methane yield (YCH_4) of 0.082 L_{CH4} g^{-1} COD^{-1}_{rem}. The theoretical YCH_4 of 0.328 L_{CH4} g^{-1} COD^{-1}_{rem} was not reached due to the low volume of methane obtained, since the metabolic activities were focused on the anabolic phase leading to a good biomass production.

The upflow anaerobic filter proved to be efficient for the treatment of poultry effluents. It requires a longer acclimatization time for the formation of biofilm in the support medium, in addition to applying a previous treatment to remove organic matter, which will allow a gradual and constant production with the application of organic loads

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