TECHNO-ECONOMIC ANALYSIS OF THE BIOREMEDIATION PROCESS FROM SWINE FARMS EFFLUENTS THROUGH MICROALGAE CULTIVATION

Keywords: Effluent; Microalgae; Anaerobic digestion.

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1. INTRODUCTION:

In recent years, Brazil has become the world's fourth-largest producer of swine meat, corresponding to 3.6 billion tons. Since the world population tends to increase, swine production will increase, bringing their problems with it (Araújo et al., 2016).

Combined with this production, there is a large consumption of water and release of large volumes of effluent from swine confinement washes and their detritus (Nwoba et al., 2016), that have large amounts of nutrients, such as nitrogen and phosphorus, corresponding from 800 to 2300 $mg.L^{-1}$ and 50 to 230 $mg.L^{-1}$, respectively. However, if this effluent is not treated or disposed of correctly, it may contribute to several environmental problems, such as greenhouse gases (GHG) emission, soil pollution, odor release, eutrophication and water acidification (Vadiveloo et al., 2020).

Thus, the treatment of swine effluent through an anaerobic digestion system (AD) combined with the cultivation of microalgae (CM) gains prominence. This integration promotes a circular economy, and swine production sustainability (Vadiveloo et al., 2020).

In virtue of this opportunity for sustainable development, this research has sought to develop a techno-economic analysis of this integrated system with AD and CM for the bioremediation of swine effluents with the generation of bioproducts, in order to reduce the environmental impacts caused by the production of swine mainly.

2. METHODOLOGY:

2.1. Definition of flowchart and process design:

The process flowchart for swine effluent bioremediation through the CM, with pre-treated effluent via AD, is represented in Figure 1. In this figure, are shown the streams with their respective flows in the agreement of their references.

The effluent from the swine farm (1) is pumped into the AD pre-treatment system (RE-DA-01). As the AD process is a covered tank, the biogas (7 and 8) is collected through a blower (SO-DA-01). In addition, fertilizers (14) are obtained with the retention of solids, and a pre-treated effluent (5) is obtained which can be used for CM. It must be emphasized that this coverage of AD improves the digestion because the system operates at mesophilic temperatures.

After AD, the pre-treated effluent went through a filter (FI-CM-01) with sand and stone to clarify the undiluted effluent. It was considered that the solids in this effluent are removed, allowing the use for CM (RE-CM-01) adding or not CO_2 (21) (Ayre et al., 2017; Nwoba et al., 2016). The tank depth of 0.2 m was considered, not being higher to not impact the photosynthesis process (Davis et al., 2011). The other dimensions and configurations followed the study of Chisti (2016), with proportional width and length in 1:10 and end in semicircle. In addition, as the CM is opened, the net evaporation rate (16) of the Southeast region of Brazil for water replacement (22) was considered. From the CM, the effluent is pumped for sedimentation (SE-CM-01) and centrifugation (CE-CM-01). At this stage, the biomass of the microalgae (20), its residues, and the treated effluent (23 and 24) are obtained, ending the process.

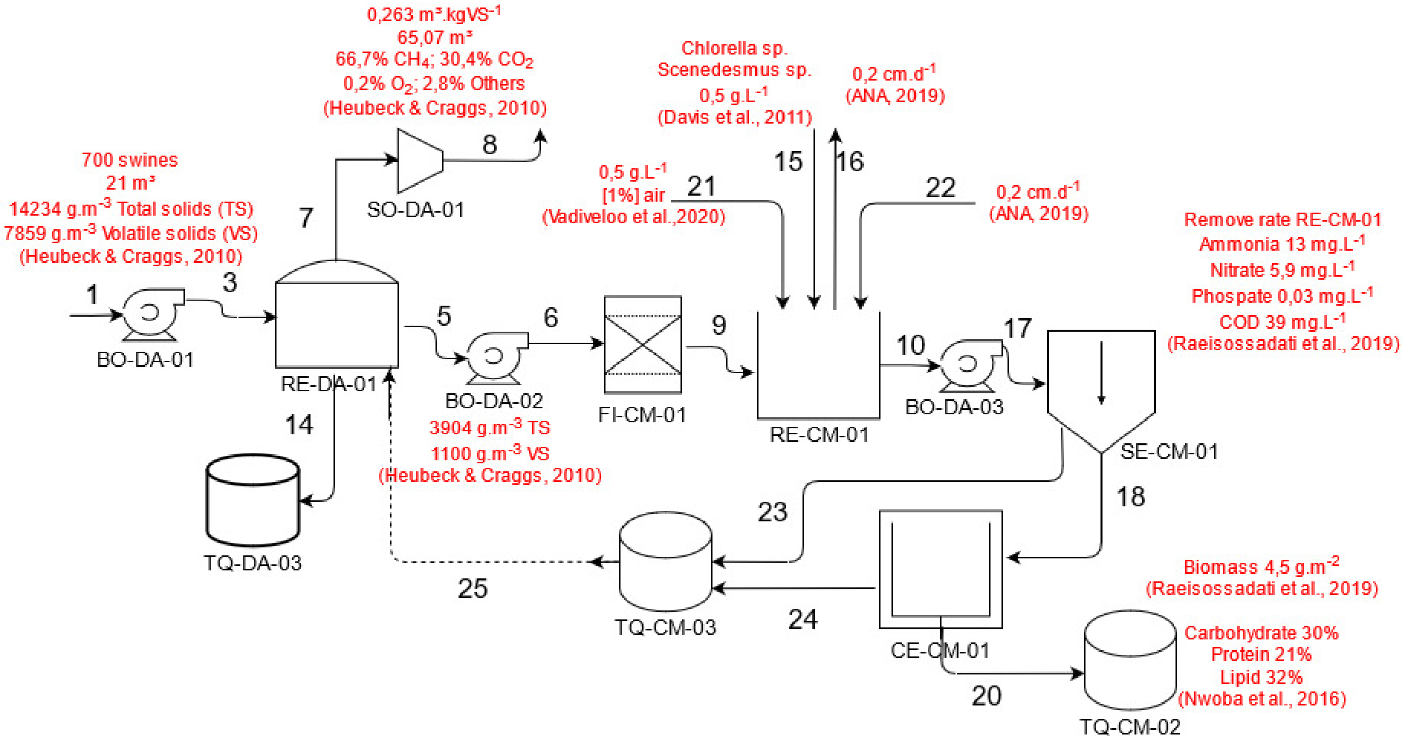

Figure 1: Process flowchart of the integrated bioremediation system.

After establishing the input and output streams considered, the mass balance of the project was carried out in an Excel® spreadsheet according to the characterizations of effluents and system, serving as the basis for techno-economic analysis.

2.2. Economic considerations:

The capital and operational costs were obtained through bibliographic reviews of economic articles from similar systems of the proposed system. Their values were defined according to each equipment's scales and budget year, obtained according to Equations 1 and 2, respectively, and performed in Excel® spreadsheet. It is emphasized that for Equation 1, the *n-th* rule with n = 0.6 was used. For Equation 2, the respective CEPCI of each year (Chemical Engineering, 2019) was used. The economic calculations were based on the USD dollar for 2019 and 20 years of operation with linear depreciation. It was considered an annual interest rate of 10%, income tax for companies in the amount of 15%, 330 days of plant operation, USD 0.18kWh price (NGSolar, 2021), maintenance 2% of installed equipment and taxes, and insurance corresponding to 1.5% (Davis et al., 2011).

$$New\ scale\ cost = originial\ cost\ .\left(\frac{New\ scale}{Original\ scale}\right)^{0,6} \quad (1)$$

$$New\ year\ cost = original\ year\ cost\ .\left(\frac{CEPCI\ new\ year}{CEPCI\ original\ year}\right) \quad (2)$$

3. RESULTS AND DISCUSSION:

3.1. System designed:

Table 1 presents the main system data obtained via mass balances in Excel®. It is emphasized that these data served as a basis for techno-economic analysis.

Table 1: Main results obtained per day with mass balance.

Parameter	Value	Parameter	Value
Effluent recovered	20.6 m³	Fertilizers (remaining solids)	218 kg
Biomass produced	477.3 g	Biogas	65.1 m³

It was noted that this treatment system presented in Figure 1 proved to be effective in treating most of the effluent that was fed and decreased in large numbers the solids present in it. In addition, an amount of biogas was generated, but there was a low amount of biomass produced. This may be linked to the fact that, in the present study, the daily productivity of microalgae was considered for the mass balance, combined with the daily hydraulic retention time in the CM and a small-scale surface area of cultivation. Biomass is the main product obtained, as it presents great possibilities of use to generate other products with higher added value (Bhattacharya & Goswami, 2020).

It is important to highlight that swine effluent is a good source of nutrients, and their use for biomass growth is the central idea of this project. This reduces the costs of CM and increases sustainability because it uses an effluent that could be poorly discarded or treated only conventionally, not taking advantage of the present nutrients, besides not having expenses with replacement of these nutrients necessaries for the CM (Craggs et al., 2014).

Moreover, obtaining co-products is important in generating alternatives for the use of resources and new earns, also to a possible generation of circular economy and greater sustainability. In the case of biogas generated, it can be: used by the farm itself to generate electricity through a generator; destined to the CM to supply the possible addition of CO_2, (improving the productivity of microalgae and generating biomethane with higher economic added value) (Klein et al., 2018); or sold in your first form. It is noteworthy that the use of biogas by the farm itself contributes to sustainability since methane (the main fraction of biogas) is retained from its release into the atmosphere.

Regarding the treated effluent, studies have indicated that microalgae were able to remove a large part of the ammonia present in it, but still had nutrients (Craggs et al., 2014), being able to use this fertilized water for agriculture provided there is a control of pathogens and maximum nutrients allowed that does not contaminate the soil. It's emphasized, in this project was not considered the cycle of this effluent to the system itself in any of its stages, since the load of nutrients and pathogens would increase more than its removal rates.

3.2. Techno-economic analysis:

After the balances of the bioremediation system, an economic study of this system was carried out as described in topic 2.4. and economic articles (Acién et al., 2012; Bravo-Fritz et al., 2016; Craggs, 2008; Davis et al., 2011; Davies et al., 2014; Martins et al., 2011; Leroy Merlin, 2021). Figure 2 represents the capital cost and operating cost and the percentages of each segment that contribute to the total.

For CAPEX, the results showed that the centrifuge and CM correspond to the highest contributions with these costs, 40.28%, and 20.26%, respectively. This is because the first is robust equipment and has better efficiency for moisture removal since it concentrates 10 $g.L^{-1}$ (sedimenter output) at 200 $g.L^{-1}$ the effluent with biomass. Thus, there needs to find alternatives to reduce this cost on biomass concentration, such as it represents close to 50% of CAPEX. About the complete CM, as it represents the costs since its implementation and construction in surface area of approximately 100 m^2, equipment and chicanes for mixing, this value is within the expected, as seen in other larger-scale studies (Davis et al., 2011).

Concerning the annual OPEX, the largest fractions of this cost are related to workers (35.27%), centrifuge (18.78%), and maintenance (17.41%). The workers' salary of USD 250.00 per month was considered and operating for 8 hours accumulated per day since it is not necessary to operate the system in continuous time. They still presented considerably high fraction value, but more due to other operating costs like equipment being low, because in this designed system there is not equipment that consumes a large amount of energy, except for the centrifuge, which appears again as one of the cost aggregators. Other studies also identified that the harvest part was the one that resulted in the highest costs in relation to the total (Davis et al., 2011).

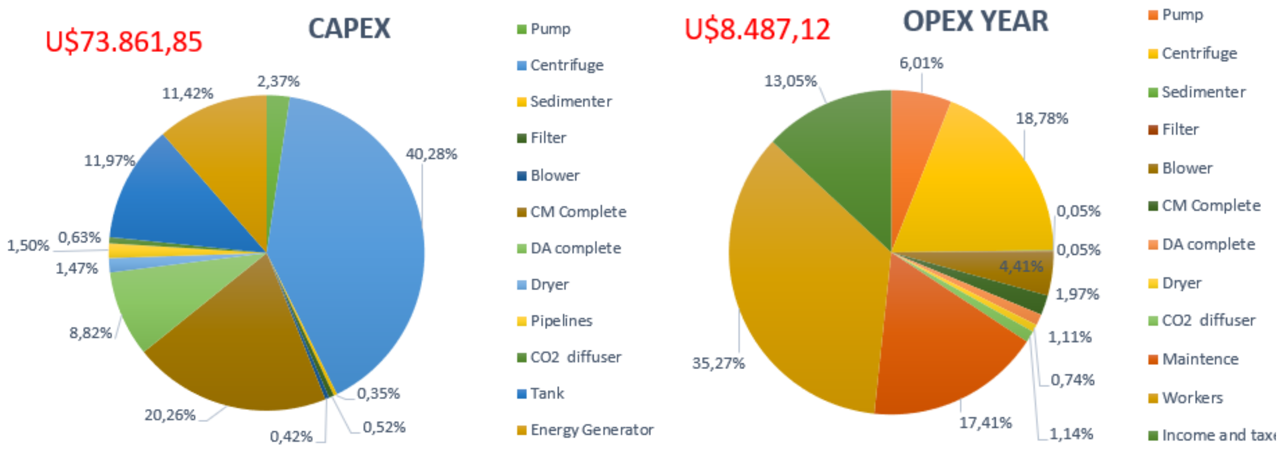

Figure 2: Results obtained for project costs.

For the capital inflows, this project considered the generation of energy by biogas and its sale, sale of fertilizers, and biomass generated, according to their prices (Bravo-Fritz et al., 2016; Spruijt et al., 2015; Viva Salute, 2021). Thus, the techno-economic analysis of the project was performed considering the cash flow obtained. When considering that biomass is sold in bran/powder to be part of animal feed supplementation, the total capital inflows for each year represented USD 14,141.83, a slightly higher value only than OPEX. With the discounted cash flow done in 20 years and the appropriate considerations presented in topic 2.4., a negative net present value of USD 32,715.07 was obtained. This value expresses that, according to the conditions presented for techno-economic analysis, mainly because of the high CAPEX and low sales value of the products considered, this system is economically unviable since it has a loss of more than U$D 30,000.00 of invested capital. For this system to be economically viable without changing the conditions of the process, only by changing the total value of sales obtained annually, it would require that the combined sale of all products reached the value of USD 20,000.00 to obtain a net present value of U$D 8,937.59, with an internal rate of return of 11.7%.

4. CONCLUSIONS:

This work may verify that the system for bioremediation of the swine effluent with AD and CM is considered promising in terms of sustainability. It was observed that this system mainly prevents methane released by the swine effluent from being ceded to the atmosphere and prevents the effluent to be discarded in nature with high nutrient loads, reducing these through the removal rates of microalgae. However, it was not economically viable because of the high CAPEX associated with the high cost of a centrifuge and the sale of products with low added value in the market. In addition, as the process is on a small scale, it also questions the productivity of biomass regarding it is associated with the surface area of the tank.

Due to these facts presented, sensitivity analysis becomes an important tool for studying possible cases that would add value economically to the process presented, looking for ways to make it viable. In addition, it’s suggested for future research to study alternatives to replace the centrifugation process for the concentration of wet biomass, considering it represented the highest capital and operational cost among the equipment.

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