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Profitability of biogas production as a source of energy for tequila distilleries from the anaerobic treatment of tequila vinasses

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ABSTRACT

Objective: To analyze the profitability of biogas production from tequila vinasses in an anaerobic packed bed reactor (PBR) plant to use biogas as substitute of heavy fuel (fuel oil) in boilers of the tequila industry.

Design/methodology/approach: Financial information for biogas production was gathered; the methodology with the approach of investment project evaluation was used for two reactor volumes, 7 m^3 and 10 m^3, and the profitability was determined through the following financial indicators: Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (B/C R).

Results: Biogas production is profitable starting from a reactor's volume of 7 m^3 and it is more favorable when the process is scaled to 10 m^3. It was obtained for a volume of 7 m^3 and 10 m^3 at an updating rate of 12% (NPV $780 376.70 and $5 062 685.22), (B/C R $1.04 and $1.21), (IRR 14% and 26%).

Limitations on study/implications: The results are based on values reached in a PBR plant at laboratory scale with a capacity of 445 L, assuming that the values of yield and removal of the chemical demand for oxygen (CDO) are not modified when scaling the process to 7 m^3 and 10 m^3.

Findings/conclusions: Analysis of the results showed that the use of tequila vinasses to generate renewable energy for auto-consumption in an anaerobic PBR plant is profitable.

Keywords: Financial indicators, anaerobic digestion, AP digester, renewable energy, biofuel.

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INTRODUCTION

During agave (*Agave* spp.) distillation, contaminant residual waters are obtained called "tequila vinasses". Between 10 and 12 L of vinasses are generated per liter of tequila produced (García and León, 2018). This effluent is characterized by having low hydrogen potential (pH), high temperatures, high concentrations of biochemical demand of oxygen (BDO) and chemical demand of oxygen (CDO). The production of biogas is a sustainable process established for the simultaneous generation of renewable energy

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and the treatment of organic wastes (Angelidaki *et al.*, 2018). For this, it is necessary to find alternative ecological sources of fuels, which requires the design of an appropriate and affordable technology (Lorenzo *et al.*, 2015). Biogas consists primarily in methane (CH_4) in a range of 50 to 70% and carbon dioxide (CO_2) in 30 to 50% (Angelidaki *et al.*, 2018). The most common applications of biogas are the direct combustion for heat production and the generation of electric energy (Venegas *et al.*, 2019). To create economically efficient biodigestion systems, it is necessary to analyze the execution of the project that allows the construction of affordable facilities and a faster recovery of the investments (Cervi *et al.*, 2011); also, to establish economic parameters that show the conditions under which it operates, in order to ease managerial, economic and financial decision making (Nava, 2009). The objective of this study was to analyze the financial profitability of biogas production from tequila vinasses in an anaerobic packed bed reactor (PBR) plant for the use of biogas as substitute of fuel oil in boilers of the tequila industry.

MATERIALS AND METHODS

The biogas production system is constituted by a series of stages illustrated in Figure 1.

The PBR plant at laboratory scale (Arreola, 2018) that produces biogas from tequila vinasses is located in the Exact Sciences and Engineering university center at Universidad de Guadalajara, Mexico.

The necessary financial information for biogas production was gathered through surveys directed toward researchers in charge of the plant. The financial evaluation model

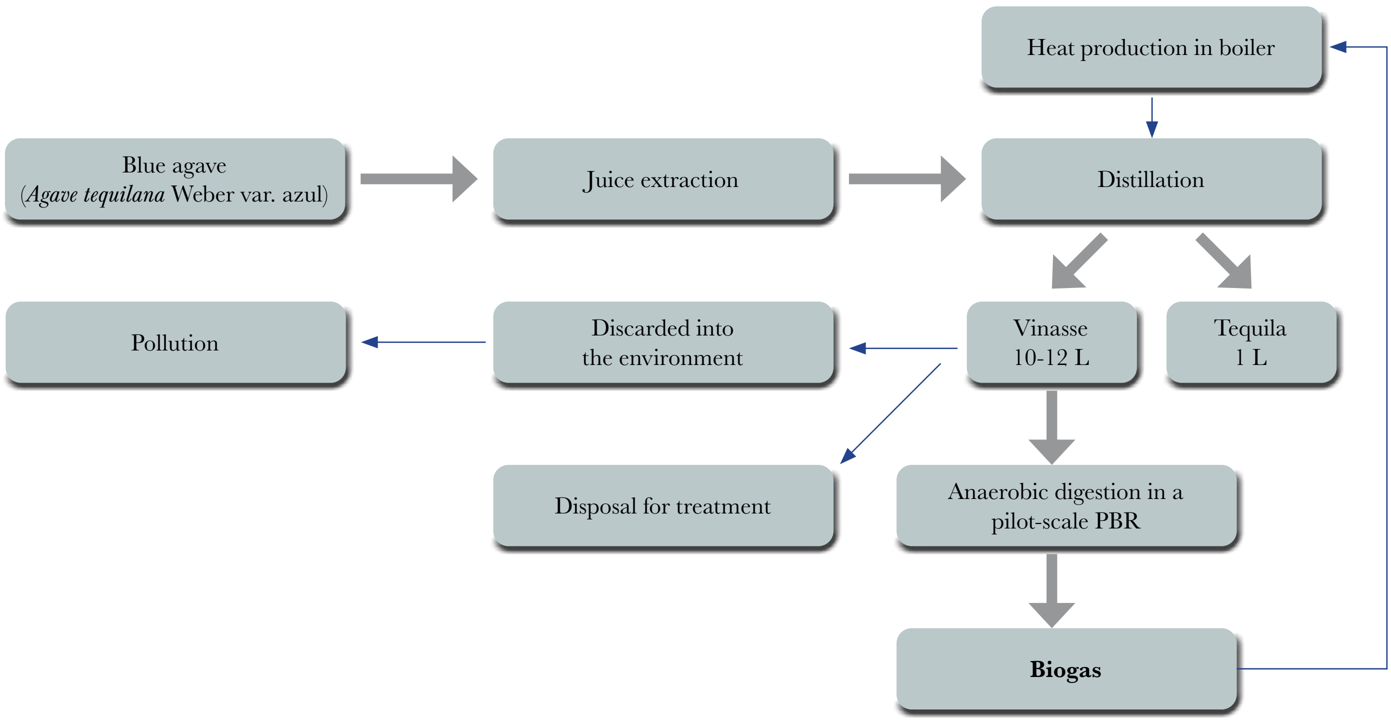

Figure 1. Production cycle of tequila, vinasse and biogas. Source: Prepared by the authors with information from interviews, 2021.

consisted in five stages: *estimation of total investment, production volumes, estimation of operations benefits and costs, calculation of the net cash flow, and financial indicators*. The economic values are expressed in current values for the year 2021 in Mexican pesos (MX). There is not a specific price for biogas in the market, so since fuel oil is the source of energy to substitute, the average annual price of fuel oil of $9.15/L MX from the year 2021 was taken as reference.

Conditions of biogas production: The production was estimated from the values reached in the PBR plant with a capacity of 445 L (base scenario), assuming that the values of yield and CDO removal are not modified when the process is scaled, 70% in biogas and raw vinasse of 60 kg/m^3. The plant operates with 75% of its capacity, with an operation period of 355 days per year. The profitability was evaluated in two scenarios, one with a reactor volume of 7 m^3 at which the project is profitable, and the second with a volume of 10 m^3 which represents the maximum volume of the reactor at which the production can be scaled based on the conditions of the system at laboratory scale. The technical data based on the reactor volume are presented in Table 1.

Investment and costs: The investment of the project was based on the working digester and the production process was scaled. The unitary costs contemplate the variable production costs (VPC) and the fixed costs (FPC), which are distributed monthly, whether there is production or not (Cisneros-López *et al.*, 2020). The annual investment, operation and maintenance costs were considered. In the variable costs, the following were included: cost of vinasse, assigned based on the cost generated for its production and harvest from the "agave" raw material $337.097/m^3; cost of electricity $1.35 K Wh (industrial fee in Jalisco) (CFE, 2021); drinking water $27.35 m^3 (fee from the zone where the plant is located) (SIAPA, 2021); and costs of chemicals $0.014/L of biogas. The fixed costs consider the following: cost of laboratory equipment, reagents for monitoring, office consumables, salaries, insurance, plant maintenance, payment necessary for monitoring and validation of the sale of CERs (carbon bonds), which is 20% of the sales of CERs each year, and five-year loan for the acquisition of the project's assets.

Financial evaluations and Profitability indicators: The methodology of project evaluation based on Baca (2013) was used, which calculates the profitability through the financial indicators NPV, IRR, B/C R and sensitivity analysis. Minimum Acceptable Rate of Return (MARR): the horizon of useful life of the project was fixed at 10 years at a MARR of 12%, which considers the bank rate from 2021 of 9% and 3% of risk.

Table 1. Technical data of the scenarios for biogas production.

	Scenario base	Scenario 1	Scenario 2
Reactor volume (m^3)	0.445	7	10
Water feeding flow (m^3)	0.099	1.55	2.2
Vinasse feeding flow (m^3)	0.049	0.77	1.1
Production of biogas (m^3)	0.95	14.94	21.3

Source: Prepared with data from the interviews, 2021.

Net Present Value (NPV): According to Baca (2013), the NPV formula is the following:

$$NPV = -I + \sum_{i=1}^{t} \frac{b_i - c_i}{(1+\partial)^t} \quad (1)$$

Where: I: initial investment; b_i benefit in time i; c_i cost in time i; ∂ rate of discount; t time or horizon of investment.

Internal Rate of Return (IRR): The IRR was determined based on Formula 2 from Weston and Bringham (1993) cited by Cisneros-López *et al.* (2020).

$$\sum_{i=0}^{n} \frac{CF_i}{(1+IRR)^n} \quad (2)$$

Where: CF: Net cash flow; IRR: Internal rate of return; n: number of periods; i: period.

Benefit-cost ratio (B/C R): It was calculated based on the formula that Cisneros-López *et al.* (2020) used.

$$\frac{B}{C} = \sum_{i=0}^{n} FI_i \, / \sum_{i=0}^{n} FS_i \quad (3)$$

Where: B: benefit; C: cost; FI: flow of income discounted; FS: flow of spending discounted; n: number of periods; i: period.

RESULTS AND DISCUSSION

The initial investment required for the project to work is $4 429 817.78 for scenario one and $4 545 118.75 for scenario two. Among investment costs, the cost of the plant stands out, which reaches $2 146 464.80 and $2 219 331.37, respectively.

Annual cost budget: The unitary cost of production for scenario one was $0.19/L and for scenario two $0.15L of biogas, which were obtained from adding the unitary variable cost of $0.05 and $0.04 L of biogas and the fixed unitary production cost of $0.14 and $0.011 L of biogas, respectively.

Annual production: In scenario one, an annual treatment is generated at 276 249.17 L of vinasses and 5 303 984 L of biogas is produced, and for scenario two 394 641.67 L and 7 577 120 L, respectively. In this evaluation, the benefit from the sale of CERs is taken into account, in agreement with Lorenzo *et al.* (2015) who mention that the bonds inject an extra cash entry. Vera *et al.* (2017) considers the benefits from the sale of CERs with a price of $7.74/ton CO_2 eq/a (annual tons of carbon dioxide equivalent) for the year 2015, and a price of $7.86/Ton CO_2 eq/a in this project.

Financial indicators: Both scenarios obtained a positive NPV, and the investment is recovered, as well as the opportunity cost of the resources. The most favorable scenario is two, as shown in Table 2.

In the B/C R, for each peso invested a benefit of $0.04 is obtained in scenario one and $0.21 in scenario two. The IRR in both scenarios was higher than the MARR of 12%, which indicates that the use of tequila vinasses such as biomass in a PBR plant to generate biogas becomes a competitive and profitable option, as is the case recorded by Lorenzo *et al.* (2015), Suárez-Hernández (2018) and Rostagno *et al.* (2020), who show the financial profitability of anaerobic digesters for biogas production from agroindustrial vinasses and residues, taking advantage of these contaminant residues and assigning them a value.

Authors like León *et al.* (2019) indicated that the digesters contribute a solution and alternative in residue management, through the use of available resources transforming them into biogas. Lorenzo *et al.* (2014), Alonso-Estrada *et al.* (2015) and López Velarde *et al.* (2019) mention that, because of the composition of vinasses, they are a promising substrate for the production of biogas and methane.

Table 2. Updated net cash flow of biogas production with tequila vinasses with a reactor volume of 7 m^3 and 10 m^3, in Mexican pesos 00/100 MX, with data from 2021.

Years/ concept	Scenario 1	Scenario 2
0	−4,736,624.88	−4,851,921.86
1	−752,888.96	−309,167.98
2	350,127.66	857,926.46
3	638,970.12	1,238,997.27
4	530,622.21	1,065,837.06
5	478,421.37	955,782.13
6	887,261.28	1,327,997.81
7	775,616.72	1,169,131.47
8	707,319.26	1,058,671.72
9	631,535.06	945,242.61
10	1,270,003.81	1,604,188.53
NPV	780,376.70	5,062,685.22
IRR	14%	26%
B/C	1.04	1.21

CONCLUSIONS

The results obtained show profitability of the project for biogas production from tequila vinasses, contributing to mitigate problems caused by vinasses (with the anaerobic treatment of residual waters), the use of fuel oil in tequila distilleries (with the generation of biogas for auto-consumption), and profitability (with the income obtained by the substitution of fuel oil, the sale of CERs and the cost reduction generated by the availability of vinasses). Biogas production from tequila vinasses with PBR digester was a profitable and competitive activity. The information from this study significantly helps to enrich the database of the treatment of tequila vinasses at laboratory scale and will help in decision making.

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