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Energy recovery from wine sector wastes: A study about the biogas generation potential in a vineyard from Rio Grande do Sul, Brazil

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ABSTRACT

The constant concern with the environment and the depletion of fossil fuels has attracted interest in renewable energy from bio resources and/or materials wasted incorrectly. The process of anaerobic digestion converts organic waste into valuable energy sources, while reducing the pollution potential of this waste to the environment. The study was designed to analyze the biogas and methane generation potential from organic by-products of wine. Using the methodology described in VDI 4630 and automated biogas quantification based on the displacement of fluids. The results showed the biogas and methane production potential of the wine biomasses, and the ones with greatest potentials are grape must, the mixture of all biomass and bagasse 1.151; 289 and 199 m^3 biogas.tonVS^{-1}, respectively. Likewise, it was verified that biomass energy recovery for methane production has the capacity to supply approximately 2% of the natural gas demand in Rio Grande do Sul. These results presented specifically the biomass characterization of the wine sector and as potential energy for the production of biogas and methane, verifying the possibility of using this form of clean and sustainable energy on a large scale.

Introduction

The wine activity is one of the leading sectors in the food processing industry. According to the International Organization of Vine and Wine (OIV) the world wine production in 2015 was approximately 280 million hectoliters or 28 billion litters, and France and Italy are the countries with the highest production, which correspond to approximately one third of the global volume [1].

According to the OIV, Brazil is the 15th country with the highest production of wine in the world (≅280 million liters), whose production is concentrated mainly in the state of Rio Grande do Sul (RS). According to the Brazilian Institute of Wine, the RS has 731 wineries legally registered in the IBRAVIN and produces about 90% of the Brazilian wine (≅250 million liters), and the cities of Bento Gonçalves, Flores da Cunha, Farroupilha, Garibaldi, Caxias do Sul, Carlos Barbosa, Cotiporã, Vila Flores, Nova Roma do Sul, Antonio Prado and Veranópolis are the largest wine producers [2].

The wine industry has become an activity of great social and economic importance in this region of the Northeast Gaucha Highlands [3]. In addition, the Atlas of the Rio Grande do Sul Biomass shows that this region generates annually about 290.000 tons of biomass from the wine sector and which can be harnessed to generate biogas and methane [4].

The wine is a traditional and seasonal process in the State of Rio Grande do Sul that varies according to the type of wine produced. In general, the process consists in harvesting, milling, pressing, fermenting, decanting, stabilizing and bottling, and in each one of these steps by-products can be generated [5].

Researches from the *Italian Agency for Environmental Protection (APAT)* evaluated the amount of waste generated in the grape wine process and found that 2 L of effluent are generated from the processing of 1 L of wine, but this value is directly related to the type of technology used. The main by-products are generated in vineyards are bagasse, stems and dregs, whose generation is estimated at 0.18, 0.04 and 0.06 kg, respectively, per liter of wine processed [6,7].

To Da Ros et al. the anaerobic digestion of the by-products from the wine production show as a very promising treatment, since it is possible to use the biogas as a source of clean energy [8]. Through the anaerobic digestion, the organic material contained in the biomass is converted into biogas, whose main constituents are methane (CH_4) and carbon dioxide (CO_2) [9,10]. Besides these, other gases are found in smaller proportions as water vapors (H_2O), hydrogen sulphide (H_2S), hydrocarbons, ammonia (NH_3), oxygen (O_2), carbon monoxide (CO) and nitrogen (N_2) [11,12,13]. Other gas production routes can be exploited through anaerobic digestion, for example the generation of hydrogen

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[14,15], however, this study will only address the generation of biogas.

The CH_4 is the most economically important gas because of its calorific power (biogas with 65% of methane has calorific value of 22.35 $kJ.m^{3-1}$) [11,12,16]. After the biogas being subjected to filtration and purification processes, it can reach 98% of CH_4 and assume characteristics similar to the natural gas vehicular (NGV). In addition to this usage, biogas can either be used as a heat source or electric power generator [17,18].

Agro industrial wastes are increasingly being used as a biomass, for generating energy. The biogas production from anaerobic digestion using different methodologies are evaluated and used throughout the world as the main source of biogas production from organic substrates [19,20,21,22]. Da Ros et al. evaluated the recycling of vineyard residues through anaerobic co-digestion with the use of activated sludge and found that the waste obtained yields of 0.40 $Nm^3.kgCOD^{-1}$ with percentages of 65% methane [8]. Liao et al. investigated the biogas generation from sludge with low organic matter concentration and found that sludge with organic content < 50% decreased biogas production to 25–30% [23]. Achkar et al. studied the potential of methane using grape pomace, pulp and seeds in the process of anaerobic digestion. They observed that the grinding of the substrates increases the maximum degradability of 22% [24]. Da Ros et al. studied the thermophilic digestion of batch wine substrates, they found that longer hydraulic retention time (HRT) and the use of co-substrates can improve biogas production [25]. Lumi et al. evaluated the biogas generation potential from animal waste supplemented with different percentage of babassu oil and concluded that the oil supplementation in 7.5% proved to be the most effective [26]. In addition, a number of other studies show that the production of biogas from anaerobic biodigestion can improve efficiency in waste treatment, overcoming energy deficits and especially by bringing an extra source of income to industries [27].

In short, the use of the anaerobic digestion process of biomass from the wine industry is an adequate alternative, because reduces energy costs and is able to improve treatment efficiencies [28], due to the seasonality of the organic load flow of the biomasses of these industries becomes favorable, once the microorganisms present enable the interruption in load flow feeding [29].

In this context, considering that the Rio Grande do Sul, especially the Gaucha Highlands has great potential for generating biomass from the wine sector, and the fact that the Gaucho Government established in the year 2016 the State Policy for the Promotion of Generation and Use of Biomethane, law n°. 14.864 [30], this study aimed to characterize qualitatively, quantitatively and evaluate the biogas and methane generation of biomass from the vinification process and, thus, contribute to the advancement of bioenergy in the State.

Methodology

The study was conducted at the University of Vale do Taquari - UNIVATES in the Bioreactor Laboratory which is equipped with an automated quantification system of biogas which is composed of reactors with a capacity of 1 l, glass tubes in "U" shape, optical sensor and a polystyrene ball connected to an electronic circuit that records and stores the biogas volume that passes through the system.

The biogas quantification occurs when the fluid level contained in it is high in its opposite side, as the gas exerts pressure on one of the sides of the "U" tube. Each time this process happens, the optical sensor that sends the information to the storage system detects it [26].

The generated biogas volume is determined by the combined equation of ideal gas where the relation among pressure, temperature and volume of a gas is constant [31]. However, when starting each experiment is carried out the system calibration, considering the temperature, volume and pressure of the calibration moment.

A sensor called Advanced Gasmitter (manufactured by PRONOVA Analysentechmik GmbH & Co) is used to determine the concentration of CH_4 contained in the biogas. The CH_4 readings were carried out every day with the injection of an aliquot of 20 mL of biogas generated in each one of the reactors. This methodology is based on the automated system of fluid displacement described by Konrad et al. [32].

Table 1
Characterization of the total, volatile and fixed solids at the beginning of the experiment (average ± SD).

Biomass	TS (%)	VS (%)	FS (%)
Triplicate 1	3.52 ± 0.04	52.88 ± 0.12	47.11 ± 0.12
Triplicate 2	4.44 ± 0.06	54.17 ± 0.12	45.82 ± 0.12
Triplicate 3	4.44 ± 0.04	53.97 ± 0.12	46.02 ± 0.12
Triplicate 4	2.46 ± 0.03	38.63 ± 0.30	61.36 ± 0.12
Triplicate 5	2.58 ± 0.04	60.36 ± 0.32	39.63 ± 0.30
Triplicate 6	4.56 ± 0.04	54.29 ± 0.10	45.70 ± 0.10
Triplicate 7	4.37 ± 0.05	54.73 ± 0.11	45.26 ± 0.11

The biomasses used (bagasse, stems, must and sludge from wastewater treatment plant) were collected at a vineyard located in the city of Farroupilha, in the Gaucha Highlands region. The inoculum pre-incubated for a period of ten days comes from the mesophilic and anaerobic treatment of livestock waste from the Biogas and the Renewable Energy Studies Center from Univates. The biomasses were packed in HDPE bottles and sent to the Bioreactors Laboratory for solids content characterization (Table 1). The AOAC [33] determinations were used to evaluate the physicochemical parameters: total solids (TS), volatile solids (VS), and fixed solids (FS).

Twenty one reactors containing 600 mL of substrate were used in this study, which were placed in an incubator with controlled mesophilic temperature (37 °C ± 2 °C) and attached to the automated system for measuring biogas volume (Fig. 1).

The reactors were divided in triplicate, according to the substrate mixture: Inoculum (Triplicate 1), Inoculum and Bagasse (Triplicate 2), Inoculum and Stem (Triplicate 3), Inoculum and Primary Sludge (Triplicate 4), Inoculum and Secondary Sludge (Triplicate 5), Inoculum and Must (Triplicate 6) and Mix - Inoculum and 43% of bagasse, 34% of Stem, 9% of Primary Sludge, 9% of Secondary Sludge and 5% of Must-(Triplicate 7).

The specific methanogenic potential (BMP) was based on the principles described in VDI 4630 norm [34] except for some alterations to the gas measurement system [26,35]. The ratio between inoculum and substrate used was 2 based on the VS. The experiment was concluded when the daily gas production was equivalent to 1% of the total volume of gas produced during the experiment.

The results obtained about the generation of biogas and methane was analyzed using the Statistical Package for the Social Sciences (SPSS), 20.0 version. We used the Shapiro-Wilk test to analyze the variables that followed the normal distribution. The variables did not show normal distribution and therefore analyses were performed using non-parametric tests (Kruskal-Wallis followed by Dunnett post hoc). The Kruskal-Wallis test was used to compare the seven samples of biomass to the degree of gas generation (biogas and methane) during the study period. The Dunnett's post hoc test was used to analyze the differences between the samples, two by two, and according to the kind of gas generated. Besides these, descriptive statistical tests were performed as average, standard deviation and variance.

Results and discussion

The bio kinetic tests were prepared in accordance with the volatile solids analysis, as shown in Table 2.

In Table 3 there are the percentage of removal and increase of TS, VS and FS after the anaerobic digestion period. The analysis showed results close to those found by [36], which carried out the characterization of the waste generated in a vineyard and also were close to the values obtained by [37], which managed from a homogenous mixture,