Biomethane Production from Cassava Juice: The Usage of Manipueira as Biomass

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With the growing demand for alternative energy sources and environmental sustainability, waste biomass has gained prominence in the energy sector due to its wide availability. This study analyzes the production of biomethane from manipueira, a toxic and highly polluting byproduct of cassava processing, and evaluates its potential as an energy source. A biodigester was used to monitor manipueira temperature and gas production over 11 days to assess biomethane generation. The process yielded 91 mL/L of biomethane, demonstrating its viability as a biomass energy source. Additionally, the low production cost reinforces the feasibility of utilizing manipueira for sustainable energy generation.
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Since 1970, the world has experienced a series of significant environmental impacts, mainly resulting from population growth, industrialization, and changes in consumption patterns. These environmental impacts have driven growing global awareness and action in sustainability activities. Initiatives such as the creation of protected areas, policies to reduce greenhouse gas emissions, the promotion of renewable energies, and sustainable agricultural practices are some of the responses developed to mitigate the adverse effects and promote an environmentally balanced future. Brazil generates tons of waste in the agricultural sector daily, most of which is disposed of inappropriately, contaminating the soil and emitting gases into the atmosphere. These gases are generated by animal confinement waste, grain cleaning waste, and produce that rots in warehouses, so adding the generation of bioenergy to agricultural production, whether through family farming or even through large rural producers, guarantees not only a reduction in the impacts caused to the environment but also an economic possibility, since, among the renewable energies available in rural areas, energy from residual biomass is more available for low-cost access and more cost-effective for the Brazilian reality [1].

Manipueira is the liquid waste from cassava pressing to produce flour and starch. Manipueira can be used as an alternative energy source for biogas production, as it is rich in carbon molecules, nitrogen, and mineral salts, which are essential for anaerobic digestion and do not require hydrolysis [2]. Through this process, the production of biogas, which is made up of a mixture of gases, with commonly 60%-70% biomethane (CH_4) and 25-35 % carbon dioxide (CO_2) as the leading gases [2], can be used as a fuel for generating thermal and electrical energy. This practice reduces negative environmental impacts and provides an alternative and sustainable energy source, promoting the circular economy and benefiting rural communities.

Firewood is often needed in rural areas for the roasting process of cassava flour. Soares (2022) [3] showed that a flour industry in Cianorte—PR replaced firewood with biogas obtained through anaerobic digestion of manipueira. The average firewood consumption between 2021 and 2022 was reduced by 50.04 %. We also observed that biogas proved more energetically advantageous as it has a higher calorific value than firewood, generating less CO_2 when burning the fuel and, therefore, better environmental performance.

Guimarães and colleagues (2019) [4] evaluated that produced electricity generation feasible in a

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quilombola community, demonstrating great social, environmental, and energy performance when using manipueira biogas to generate electricity. According to the authors, the preparation of must and the use of inoculum indicated that the biogas potential is 1.389.312 cm^3 per year in a single-stage biodigester with a capacity of 60 liters, producing 115.776 cm^3 per round. The project is also estimated to generate 214 kWh/year of electricity. In this case, animal-origin inoculum was used, which provides more excellent conditioning for CH4 production. Finally, this is another example of the excellent energy potential that can be exploited for any site that produces manipueira in residual form.

According to Kunz and colleagues (2022) [5], anaerobic digestion involves four key stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis; each plays a crucial role in converting organic matter into biogas. In Alves and colleagues (2024), it is shown that the phases of anaerobic digestion occur as follows: hydrolysis: Complex organic matter → Simple compounds, acidogenesis: Simple compounds → volatile fatty acids (VFAs), alcohols and other intermediates, acetogenesis: VFAs, alcohols and intermediates → acetic acid, H_2 and CO_2 and finally methanogenesis: acetic acid, H_2, and CO_2 → CH_4 and CO_2 [6]. In the case of manipueira, which is liquid waste, producing flammable gases requires two phases in the biodigestion process: acetogenic and methanogenic. In the acetogenic phase, bacteria in an acidic environment with a pH between 5 and 5.5 will form the main products for the methanogenic phase, including acetate, which can account for up to 70 % of CH_4 production [7]. In the methanogenic phase, microorganisms use acetate, hydrogen, and CO_2 to form biogas in a neutral pH environment. In both phases, the ideal temperature should be 15-45 ºC, where anaerobic digestion occurs [2]. Biodigestion has the advantage of taking place in low-cost and simplified biodigesters, making biomass energy sources more accessible [7].

In this context, this work aims to verify the production of CH_4, analyzing in a mixed way the feasibility of a low-cost project, which can be used, for example, in rural areas that generate biomass as waste from the main product, as occurred in Soares (2022) [3] and discussed by Bley (2009) [1]. This was done in a digestion process inside an automated biodigester, capable of cataloging the generation of CH_4, a gas of interest for energy purposes and generated in the digestion process [7]. Automation was done using Arduino and sensors, which took daily measurements. The project's low cost influences its methodological simplicity, which could make any significant production of flammable compounds viable as an aid to conventional energy sources.

Materials and Methods

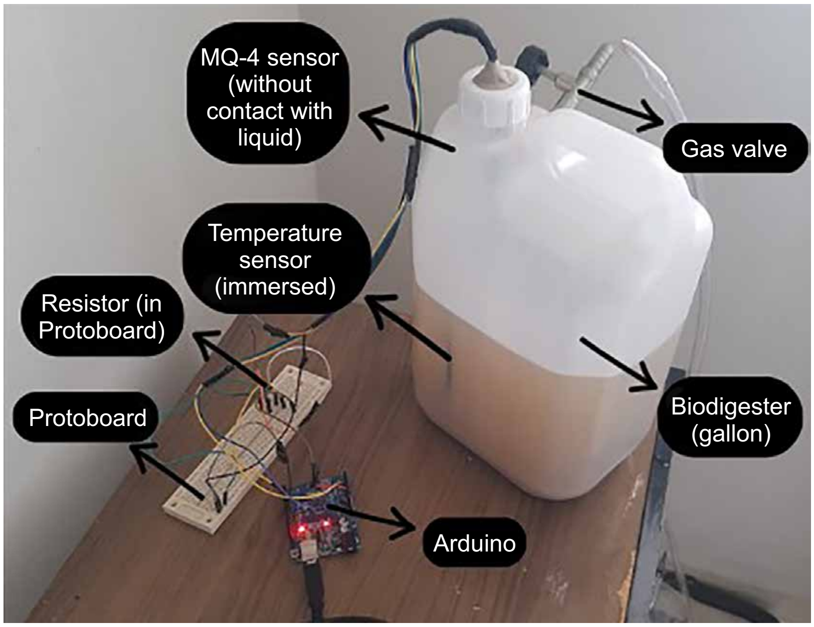
Manipueira was collected from local cassava processors in Irará (Bahia-Brazil) on May 11, 2024. The samples were then pre-treated using decantation and filtration to remove larger solids. The acetogenic phase took place in an open plastic biodigester for 4 days. Subsequently, with the pH measuring 4.7 in the acetogenic phase (conventional tape pH meter), 3 liters of manipueira were neutralized with 500 mL of NaOH at a concentration of 1 mol/L, reaching a pH of 7.1 to suit the methanogenic phase in biodigestion. The sample was then transferred to a simple closed biodigester with a capacity of 5 liters, operating at room temperature of approximately 27 ºC, and kept in a shaded location in Irará (Figure 1).

The bioreactor (Figure 1) was equipped with inlet ports for the pre-treated manipueira at neutral pH 7 and an outlet for the biogas generated by a valve. Properly sealed with epoxy glue putty to create an anaerobic environment suitable for bacterial activity and gas storage, an Arduino board was used to operate the data from the submerged temperature (DS18B20) and CH_4 (MQ-4) sensors.

The body of the biodigester comes from recycling, and the Arduino is connected to the sensors via a protoboard, which is used to connect a 4.7 kΩ resistor to stabilize the temperature sensor reading signals.

In the same line, Alves and colleagues (2024) presented an automated biodigester that controls

Figure 1. Biodigester.



the temperature and monitors the formation of hydrogen and CH_4 in real time, as well as the pressure and temperature control variables [6].

Their results indicated higher biogas production at around 35 ºC [6]. This work demonstrated that manipueira can produce biogas even in conditions without temperature control and without the need to add inoculants, so this technology can be implemented in rural areas that do not have access to more sophisticated equipment.

<u>System Configuration</u>

Sensor connection: The Arduino's input ports must be connected to the sensors. The DS18B20 sensor needs three wires (signal, ground, and power), while the MQ-4 is connected to the Arduino's analog input ports. Arduino programming: The code was developed to read sensor data using Excel. Its structure is simple and available from the manufacturer on online sites.

<u>Sensor Calibration and Data Collection</u>

The sensors were calibrated before continuous use to ensure the accuracy of the readings. This includes sensitivity adjustments for the CH_4 sensor and checking the temperature sensor's accuracy. The collection is done with a GPU connection to the Arduino, which has been configured to export the temperature reading in degrees Celsius and the CH_4 volume in part per million directly to the Excel platform.

Results and Discussion

Upon initiating the bioreaction, a 12-hour interval was established for measuring CH_4 production and depressurizing the biodigester, owing to its basic sealing mechanism.

Measurements were systematically recorded at 8:00 PM and 8:00 AM daily, corresponding to nocturnal and diurnal readings. Table 1 presents the measurement days, the quantity of CH_4 generated at successive time intervals, and the temperature at the time of measurement. The data reveals that 12 hours after neutralizing the pH of the manipueira and confining it in the biodigester, a production pattern emerges, which remains consistent over the subsequent 3 days for the morning measurements. Production levels are observed from May 18, the fourth day, with a more significant rise in the afternoon. This aligns with the findings of Kunz and colleagues [5], which indicate that the daytime production interval results in higher temperatures than nighttime. The increased incidence of light during the day also enhances bioremediation by activating methanogenic microorganisms more effectively.

Figure 2 shows the daily production of CH_4, adding up the values in Table 1, which is the biogas part of interest. The curve grows approximately linearly over the days up to the 5^{th} day, with production increasing significantly on the 6th and 7^{th} days. According to Neto and colleagues (2010), this is due to the reproduction of methanogenic microorganisms, in which the non-use of inoculum does not allow fermentation to be so expressive, especially at the beginning [2]. After the 7^{th} day, there is a drop in daily production, which returns to the constant trend of the curve from the 9^{th} - 11^{th}, with a slight slope. This suggests that production is significant over the next few days, from day 11 onwards, although not cataloged in this study.

Figure 3 shows the accumulated volume production of CH_4. The production was evaluated in 11 days of fermentation. It is possible to see the viability of the process, given the proportion at the end of the 11^{th} day of 91 mL of CH_4 per liter of manipueira cataloged. Although the production of this work is lower, proportionally, than in Neto and colleagues (2010) [2] or Guimarães and colleagues (2019) [4], for example, it is still possible to characterize the viability of the work since the costs are minimal and on a larger scale can generate great low-cost/benefit energy potential that is simple to obtain in terms of preparing the biomass and the biodigester [2,4]. This production tends to be even higher over a more extended period, as the curve in Figure 2 still shows excellent production on day 11. Including an inoculum with a more significant presence of CH_4-producing microorganisms and efficient temperature control can significantly increase biogas production.

Conclusion

This work shows that the production of CH4 from manipueira, a fluid derived from cassava, can reach up to 91 mL of CH_4 per liter of manipueira in the bioreaction process in the first 11 days. Daily production showed a notable increase after the 6^{th} day due to the natural proliferation of microorganisms in digestion. Daytime production

Table 1. CH_4 production.

	Night production		Daytime production	
Date	Temperature (ºC)	Volume (mL)	Temperature(ºC)	Volume (mL)
05/15	27.75	9.34	29.19	14.08
05/16	27.56	8.67	27.94	13.01
05/17	26.31	9.44	27.87	14.16
05/18	25.81	10.27	25.87	15.40
05/19	25.25	11.03	26.56	16.54
05/20	25.69	14.18	27.87	21.27
05/21	26.00	13.94	26.36	20.91
05/22	25.19	10.96	26.50	16.43
05/23	25.81	13.39	27.56	20.08
05/24	25.81	13.56	27.56	20.33
05/25	26.06	12.76	26.00	19.14

Figure 2. Biomethane daily production.

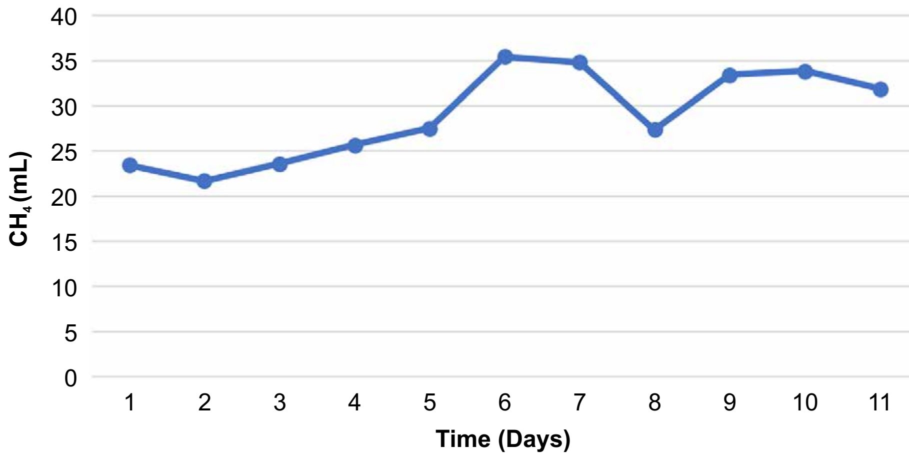
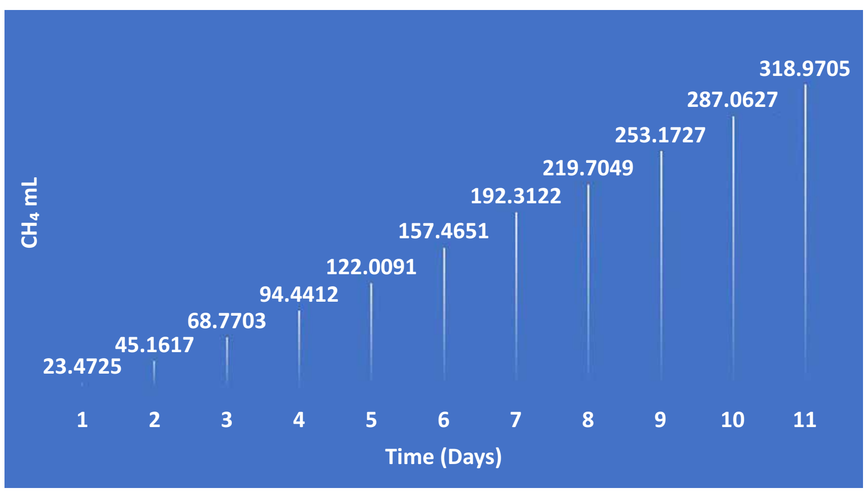


Figure 3. Biomethane accumulated production.



was higher than nighttime production, with production almost doubling after the 6th day due to the incidence of light and temperature, which increases the activity of anaerobic microorganisms. The cataloged production of 91 mL of CH_4 per liter is limited to the sampling period of the work, 11 days, the non-use of inoculums, and a more simplified biodigester methodology. Given the relative production cataloged, these decisions make the process very cheap for large-scale production and make using biomass as an energy resource viable. However, for more elaborate processes with a more extended sampling period, the amount of CH_4 cataloged could be much more significant and obtained more efficiently over days.

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