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Biogas from biodigester as energy source for Stirling engine prototype constructed from recyclable materials

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Abstract: *Fish farm and fish industries production has been growing steadily, being great food sources and nutrition in Brazil and others countries. Its development also leads to an increase in the organic solid wastes generation such as fish viscera, which, due to incorrect destination, result in environmental problems and other adversities. Therefore, it is pertinent to verify the feasibility of using fish viscera as a carbon source for biogas production and as biofertilizer, through anaerobic digestion process by the construction of a biodigester prototype aiming to produce organic fertilizer and biogas. Such gas can be used as an energy source for Stirling engine, as this type of engine can use this fuel as heat source for conversion into mechanical energy, and this type of engine have been more efficient than diesel and gasoline engines. In this way, biogas obtained from a biodigester with fish viscera and bovine manure was used as heat supply fuel for Stirling engine prototype built for this research. From a quantitative analysis of the engine mechanical and thermal data, an average percentage efficiency of 19.99% and average speed of 328.31 rpm was obtained.*

Keywords: *Biodigester, stirling engine, energy.*

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I. Introduction

Designed by Scottish brothers Robert and James Stirling in 1816, Stirling engine is classified as an external combustion engine very different from the traditional internal combustion engines or steam engines, since it has the potential to use any heat source as fuel, being more efficient than Otto cycle engine and diesel cycle. Some prototypes built by the Dutch company Phillips in the 50s and 60s achieved 45% efficiency, easily surpassing gasoline, diesel and steam engines (efficiency between 20% and 30%) [1].

Operation principle of Stirling engine basically consists of a thermodynamic cycle that encompasses four phases and runs in two piston being stages: isothermal compression, isovolumetric heating, isothermal expansion and isovolumetric cooling [2]. This operation principle closely approximates to Carnot Cycle, in which the maximum theoretical limit of thermal machines performance was defined. Stirling engine draws attention to its simplicity, as it operates by two chambers at different temperatures that heat and cool a gas alternately, promoting expansions and cyclic compressions, making the two pistons connected to a common axis moving around [3]. Stirling engine is truly multi-fuel, using virtually any source of energy: gasoline, ethanol, methanol, natural gas, diesel, biogas, liquefied petroleum gas (LPG), solar energy, geothermal heat and others [4]. Its major disadvantage is that it is difficult to start and to vary its speed of rotation quickly, being complicated its use in vehicles like cars and trucks, although models of hybrid propulsion (electric and thermal motor) can be viable [5]. In this way, biogas is presented as a biofuel similar to natural gas, being a source of renewable energy that can be obtained naturally or artificially, being flammable and with similar calorific value to other fuels. Composed mainly of carbon dioxide (CO_2) and methane gas (CH_4), its production depends on factors such as fermentation, temperature, humidity, acidity and the oxygen absence to be formed. Naturally it is produced by methanogenic action of microorganisms on food debris, animal manures, industries organic waste that work with fish and other accumulations of organic materials. It may already be artificially produced, measured and stocked by chemical bioreactors called anaerobic biodigester [6]. Biodigester is a tank containing organic materials that will be metabolized by anaerobic bacteria, protected from atmospheric air contact, where biogas will be obtained and a biofertilizer will decant at the reactor bottom [7]. This biofertilizer improves the biological, chemical and physical quality of soil with its application, obtaining a better index of nitrogen fixation by microorganisms action of this one (nitrogenous bacteria), even containing some already solubilized nutrients. The carbon content in biomass decreases through the digestion inside the reactor increasing its capacity of fertilization. Biofertilizer acts as acidity corrector by having a pH level around 7.5 [8].

This work aims to use biogas from a built biodigester, using fish viscera and bovine manure, as fuel to supply heat to a Stirling engine prototype built during the research with potentially recyclable materials, observing the effectiveness of this energy conversion system through thermal parameters to be analyzed during engine operation.

II. Materials and Methods

The materials used as well as the methodology applied for this research development were basically divided into two parts: biodigester and Stirling engine.

1.1. BIODIGESTER USED MATERIALS

For biodigester construction, potentially recyclable materials such as polyvinyl chloride (PVC) pipes, lids, hoses, wooden platform and others were used as shown in Table 1.

Table 1 – Used materials for biodigester production.

Material	Quantity	Dimensions
PVC pipe	3	5 cm; 7,5 cm;10 cm
Bucket Plugs	2	7,5 cm; 10 cm
Ball type registration	1	½ inch
Hose	1	Unit
Wood Deck	1	Unit
Pipe tail	1	Unit
Silicone glue	1	Unit
Epoxy resin type adhesive	1	Unit

1.2. BIODIGESTER CONCEPTION METHOD AND FUNCTIONING

Anaerobic reactor prototype was designed with coaxial tubes of different diameters, one internal of 05 cm diameter functioning as the organic material fermentation chamber and another external of 10 cm diameter, both with 50 cm height. Between the 05 and 10 cm tubes, the empty space was filled with water serving as hydraulic seal. A third 7.5 cm by 57 cm high gas accumulation tube (gasometer) was positioned between the two other pipes with the top side capped, dipped in an external water seal that prevents biogas leakage to atmosphere as shown in Fig. 1, reducing losses during the production process and vertically raising the gasometer as biogas concentration increases inside the reaction vessel.

A 1/2 inch valve was attached to its top for biogas removal. The produced biogas volume measurement was performed with a measure tape marking the height of the upper cylinder elevation. Finally, a hose was connected to the valve aiming to conducting the biogas to the exit where the combustion will be carried out. Because it is a batch type biodigester built with a maximum capacity of 981.25 cm3 of organic material, its supply was only done once, maintaining its fermentation for an appropriate period and after the end of the biogas production effective period the material was discharged.

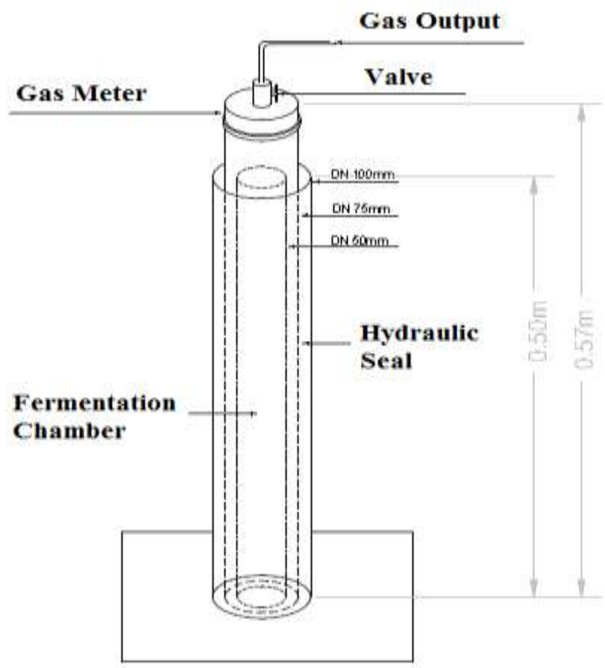


Figure 1 – Biodigester scheme using PVC pipes.

To determine the volume of the fermentation chamber the geometric solids formula was used as observed in (1).

$$V = \pi . r^2 . h \qquad (1)$$

As the projected reactor had a radius of 2.5 cm and 50 cm height, the reactor supports a volume of 981, 25 cm³.

In order to identify possible statistically significant differences in biogas production, in the use of fresh and frozen viscera, the chi-square (X^2) test was performed with the significance level (α) of 5% using the formula observed in (2).

$$\chi^2 = \sum (Fo - Fe)^2 / Fe \qquad (2)$$

Fo is the observed measurement frequency of the upper cylinder elevation and *Fe* is the expected frequency.

The ambient temperature was measured using a mercury thermometer with a temperature range of 20 to 100 ° C. It was not possible to measure the prototype internal temperature, pH and other gases produced due to the lack of equipment needed to acquire these data.

Biomass used for biogas production consisted of gravimetric mixtures of 40, 50 and 70% (by mass) of the reactor total capacity, placed inside the 5 cm duct, with viscera and bovine manure ratios of 1:1 (g/g), consisting of 200 g of each in the first experiment (fresh viscera) and 250 g of each in the second experiment (viscera frozen for two weeks), and 20% of manure viscera containing 500 g of viscera and 100 g of manure in the first and 400 g of viscera with 20 g of manure in the second experiment as shown in Fig. 02. The manure was mixed with the viscera by having the microorganisms responsible for anaerobic digestion steps.

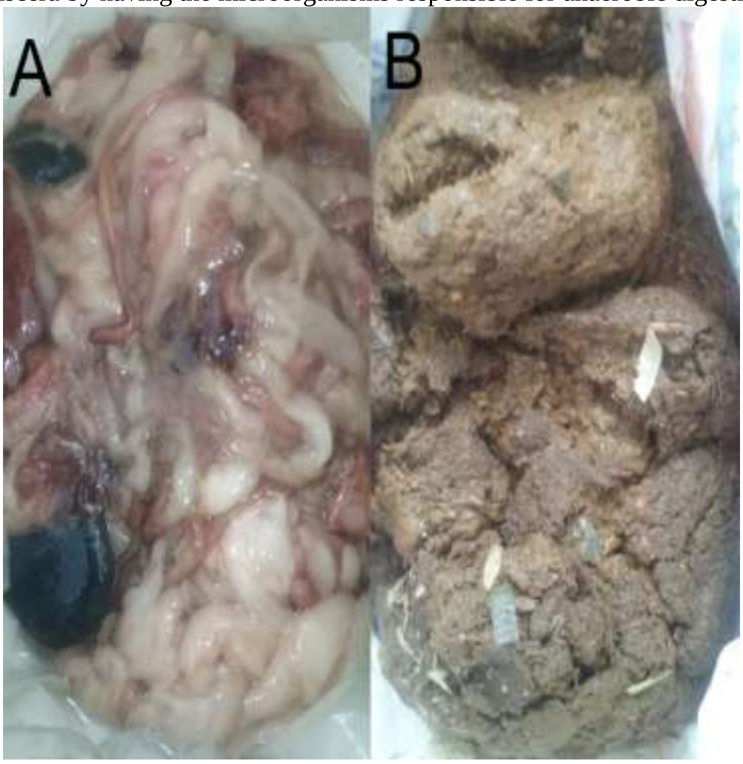


Figure 2 – Utilized sources of carbon: A) Fresh viscera and B) Bovine manure.

The material was weighed and the viscera crushed in a blender aiming to increase the contact surface, to facilitate mixing with the inoculum due to its pasty shape. Viscera and bovine manure were mixed in a beaker and, with the aid of a spoon, placed in the fermentation chamber of the organic material Fig. 03. Subsequently the upper cylinder was added to the gas tank and then the hydraulic seal. The contents were kept in the reactor for about 10 days controlling the biogas production variation by the tape measure observation.

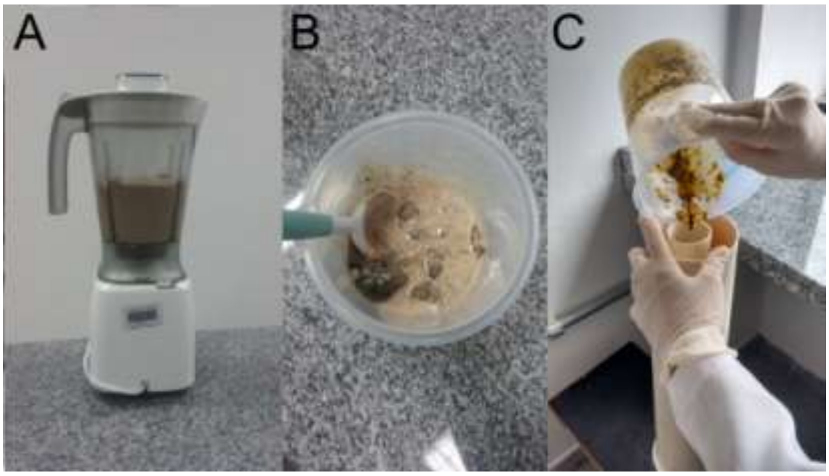


Figure 3 – Organic material preparation: A) Fresh viscera trituration, B) Viscera mixed with manure and C) Biodigester filling.

1.3. STIRLING ENGINE USED MATERIALS

The used materials for Stirling engine construction are listed in Table 02.

Table 2 – Used materials for Stirling engine construction.

Material	Quantity
Aluminum cans (coolant)	02 unities
Tuna can	01 unity
Milk can	01 unity
Stainless steel sponges	02 unities
Clips 8/0	02 unities
0.4 mm nylon wire	01 meter
Sindal connector metal parts	05 unities
Epoxy resin type adhesive	01 unity
Silicone glue for high temperatures	01 unity
CDs	04 unities
Plastic Ballon	01 unity

1.4. STIRLING MOTOR CONCEPTION METHODS

Stirling engine was constructed based on Fig. 04 and Fig. 05 shows the engine after assembly.

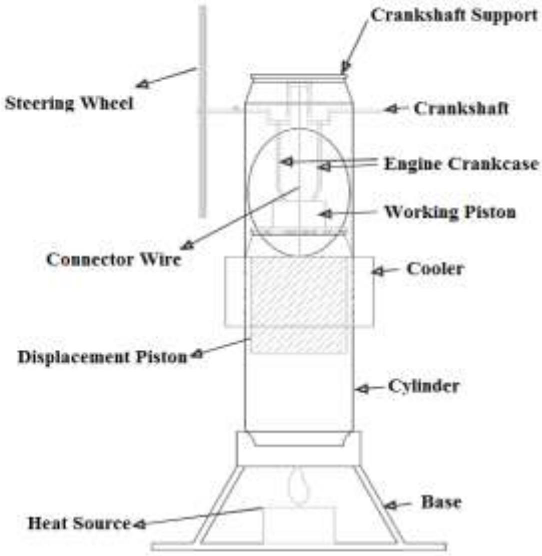


Figure 4 – Stirling engine assembly scheme.

The engine construction start with the construction of the cylinder and the heat cooler in which the top of an soda can was removed from the bottom part of the tuna can, leaving them to be poured for the two to be glued. The function of the cylinder is to support the piston that will compress the gases, and the cooler to give more thermal capacity to the cold source so that it does not heat quickly. Then the displacement piston was built using a steel sponge and a nylon thread, its main function is to move the mass of air above it to compress the bladder making movement [9].

The piston was made by using a balloon, a pet bottle closure with cap and clips, its purpose is to give strength to rotate the crankshaft realizing work. To crankshaft construction a clip was aligned to make markings and fold them into crankshaft shapes to connect the working piston and the displacement piston. The crankshaft support was built by removing the lower and the side parts of aluminum can and its function is to stabilize the assembly (working piston, displacement piston and crankshaft). The steering wheel was produced by the union of 4 CDS, Sindal electrical connectors and epoxy resin glue and its function is to stabilize the crankshaft movement. And at last the motor support was made with a milk can.

1.5. EQUIPMENT UTILIZED FOR MEASUREMENT

Measurements to estimate efficiency in the biogas use as heat source in the Stirling engine were obtained from the analysis of thermal and mechanical parameters obtained through the use of the measuring equipment presented in Table 3.

Table 3 – Equipment and realized measurement.

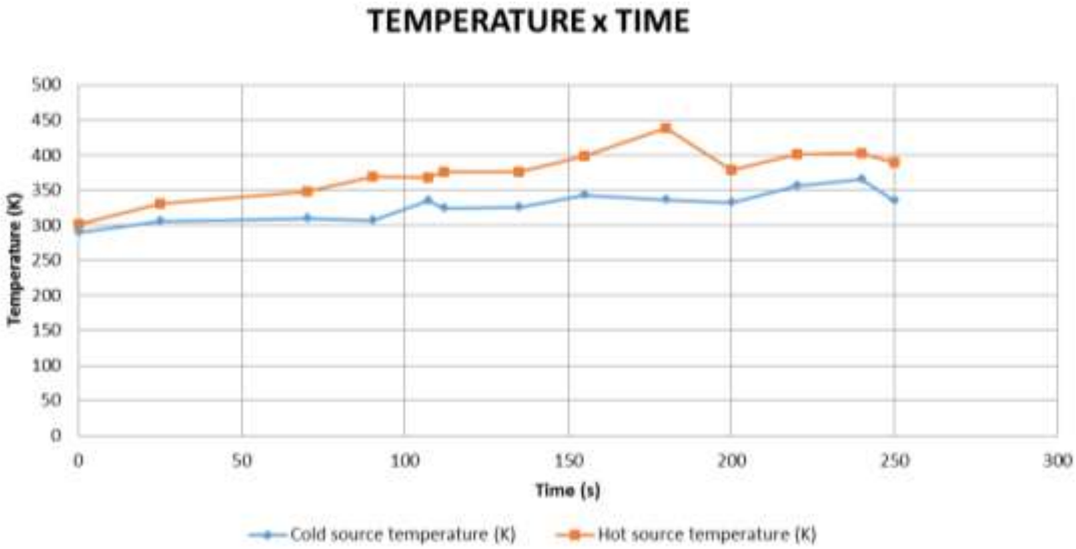
Material	Quantity
Pyrometer Raytek, RAYMX4PB	Hot and cold sources temperature during engine operation (ºC)
Tachograph PROVA TDR-800	Engine rotation speed (RPM)

III. Results and Discussion

The anaerobic reactor prototype used to obtain biogas showed efficiency in its operation, as it was possible to prove the existence of biogas by burning the fluids obtained from the biodigester, according to Fig. 5.

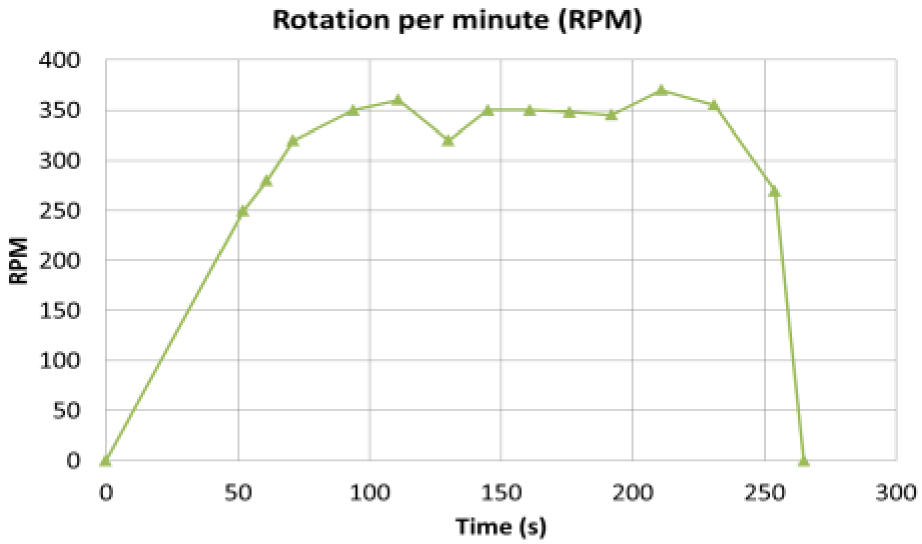
Figure 5 – Burning of the gas obtained from biodigester.

By feeding the Stirling engine with the heat obtained from biogas burning it was observed the parameters of temperature in the hot and cold sources and the rotation per minute (RPM) of the flywheel coupled to the used engine prototype. The results are shown in Graph. 1 and Graph. 2.



Graphic 1 – Hot and cold source temperature analysis.

Graphic 2 – Rotation per minute (RPM) analysis.



From obtained results, it is observed that the difference between hot and cold sources varied considerably during the engine operation, and its rotation was stabilized with about 100 seconds at approximately 350 rpm. With the measured values, the calculations of the average percentage efficiency and rotation per minute were elaborated and are presented in Table 4.

Table 4 – Results for average efficiency and rotation per minute calculations.

Parameter	Value
Average percentage efficiency	17,99%
Average rotation per minute	328,31 RPM

IV. Conclusion

The built beta-type Stirling engine worked as expected using the energy from biogas obtained at the biodigester effectively, successfully converting chemical into mechanical energy from obtained heat through the burning of the biofuel in question.

The measured data about values of rotation, hot and cold source temperature and engine efficiency, during the Stirling engine operation, were obtained. The average value of engine efficiency and the rotation per minute during the engine operation period using the same biogas as fuel was 17.99% and 328.31 RPM respectively. The sustainable biogas production system, based on the use of organic residues and subsequent heat use from the burning of this gas to fuel the Stirling engine, proved to be effective, also highlighting the possibility of reuse and recycle of materials for construction of both systems at prototype level.

Acknowledgements

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