COMPARATIVE ANALYSIS OF ENERGY GENERATION IN MICROTURBINES USING BIOGAS, BIOMETHANE, AND GREEN HYDROGEN

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ABSTRACT

Biofuels play a key role in the global energy transition and decarbonization of the planet. This study evaluates the performance of a 200 kW micro gas turbine (MGT) fueled by biogas, biomethane, and green hydrogen. We model and compare the mass flow rates required for each biofuel, highlighting their lowest calorific values (LHV). Biogas, with its lowest methane content, requires the highest mass flow, while hydrogen, with its highest energy density, requires the least. The analysis supports MGTs as a sustainable alternative to diesel generators, especially in rural areas. Future work will focus on implementing demonstration systems for practical applications.

Keywords: Biogas; Biomethane; Green Hydrogen; Micro gas turbines

INTRODUCTION

Brazil's final energy consumption is projected to grow at 2.2% annually until 2030, with residential consumption reaching 226 TWh/year by 2034 [1-2]. To meet the increasing demand for 24/7 renewable energy, biofuel-powered microturbines offer a solution for efficient electricity generation, especially in off-grid areas. The World Energy Outlook 2023 emphasizes the role of biogas, biomethane, and green hydrogen in decarbonizing the energy sector, with biogas showing great potential for replacing fossil fuels and reducing global warming through electricity and hydrogen production. [2]

Biogas is produced through the anaerobic digestion (AD) of organic material. It consists primarily of CH_4, ranging from 55% to 65%, along with 35% to 45% CO_2, hydrogen sulfide (H_2S), and other trace gases.[3]

Numerous studies have modeled and evaluated the use of gas turbines, combined cycle systems, and engines to generate energy from gas fuel. [3-10].

Recent research evaluated the thermal performance and economic viability of co-firing biogas and natural gas in gas turbine combined heat and power (CHP) systems. It found that the gas mixing ratio not only affected thermodynamic performance but also influenced retrofit feasibility and financial metrics such as payback period and net present value (NPV) [4]. Micro gas turbines (MGTs) are small, compact, high-speed turbogenerators, typically ranging from 28 to 200 kWe.

The objective of this study is to model and compare the biofuel demand of a 200 kW micro gas turbine, with the aim of understanding the different mass flow rates of biogas, biomethane and hydrogen. Based on these simulations, this research aims to provide a comparative analysis that supports the transition to more sustainable energy sources, updating diesel consumption in power generation in urban and rural areas. Future research should focus on the development, implementation and monitoring of a demonstration system.

MATERIALS AND METHODS

MGTs operate on the Brayton cycle and typically include a centrifugal compressor, a radial turbine, and a rotor with a permanent magnet alternator, as part of the core system design, as illustrated in **Figure 1** [10]

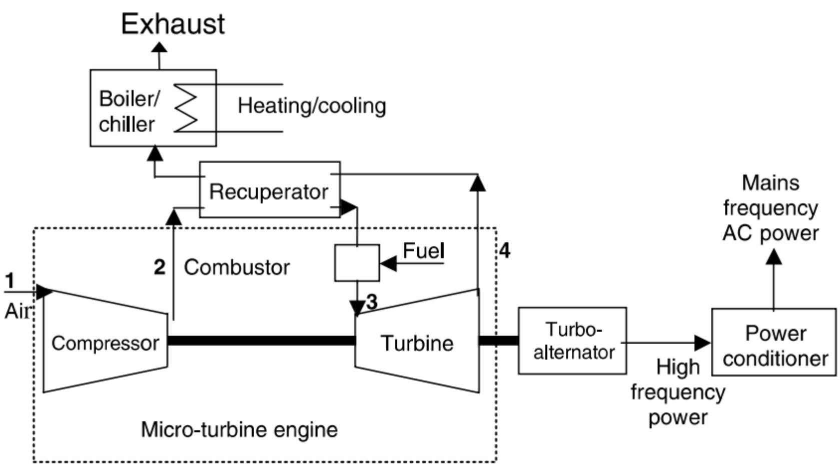

Figure 1. Schematic of recuperated micro-turbine system.

To understand the biogas production process, the configuration system with the application of the microturbine as shown in **Figure 2.** [8]

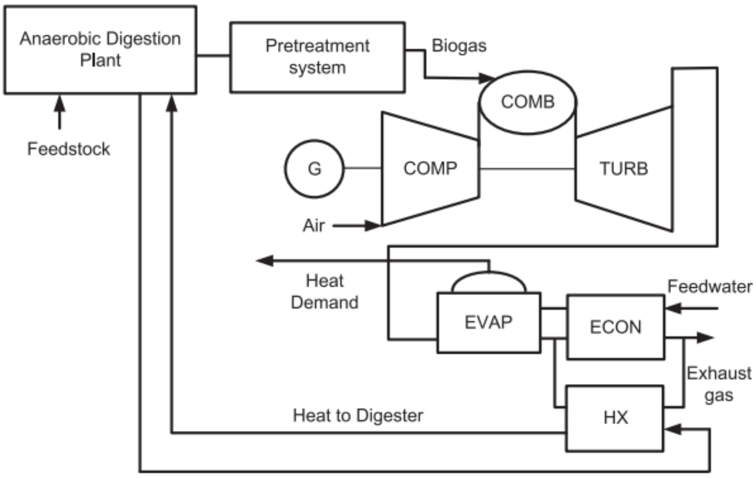

Figure 2. Combined heat and power system configuration.

The Brayton cycle, used in most gas turbines, is a thermodynamic cycle consisting of four key processes: adiabatic compression, constant pressure heat addition, adiabatic expansion, and constant pressure heat rejection [10].

The low heating value (LHV) used in this paper for thermodynamics calculations and biofuel demand for combustion calculations for biogas with 65% of CH4 is 20.223,15 kJ/kg, biomethane with 99% of CH4 is 48.814,03 kJ/kg and Hydrogen 140.000,00 kJ/kg [3 - 10].

Table 1 shows the efficiencies considered in the modeling of this case study.

Table 1. Efficiencies values.

Efficiency Va	Value (%)
Compressor efficiency (η_c)	73,00
Turbine efficiency (η_t)	68,00
Mechanical efficiency (η_mechanical)	93,00
Combustion efficiency (η_combustion)	90,00
Generator efficiency (η_generator)	82,00

The equations [3 - 10] for mathematical modeling for fuel demand simulations of each biofuel were implemented in python code to accurately simulate the fuel rates required for sustain the 200 kW MGT. The MGT construction characteristics will be maintained in each biofuel so that we can calculate the biofuel demand in each biofuel cycle.

RESULTS AND DISCUSSION

The results of the calculations are shown in table 2. It is observed that to keep the MGT in operation, the mass flow rate needs to change for each biofuel.

Table 2. Mass Fow Rates.

Biofuel	kg/s
Biogas	0,013401
Biomethane	0,005552
Hydrogen	0,001936

Biogas was the biofuel with the highest demand, followed by biomethane and green hydrogen, which had the lowest demand. This variation is a result of the lower calorific value (LHV) of each fuel. Biogas is the fuel that, because of its lower methane purity, has a lower LHV and these characteristics mean that a larger amount of fuel is needed to keep the microturbine running in the case of biogas, while hydrogen, which has a much higher LHV, requires less fuel to produce the same amount of energy.

CONCLUSION

This study showed that a MGT can run with any biofuel in gaseous form, requiring a change in mass flow rate due to the lower calorific value. The higher the lower calorific value, the less fuel the MGT requires.

A MGT can replace thousands of diesel generator sets that exist in urban centers and provide steady, dispatchable energy to the agribusiness sector with a very low rate of greenhouse gas emissions, or none of them when operated with green hydrogen.

Biogas is a biofuel with an enormous potential in Brazil and when we use it in the electricity sector can act as an energy transition and decarbonization vector, especially for agribusiness due to the organic matter supply from biodigesters.

Hydrogen has the greatest energy potential using a substantially smaller amount of mass to generate the same amount of energy. However, challenges remain concerning its transportation and storage costs.

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