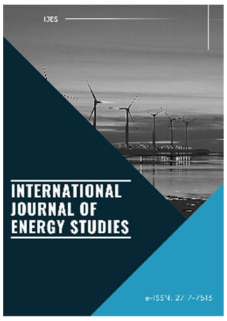
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article
Int J Energy Studies 2024; 9(2): 239-253
DOI: 10.58559/ijes.1478383

Received : 04 May 2024
Revised : 15 May 2024
Accepted : 22 May 2024

Effect of alternative biogas-methane fuels use on performance and emissions in turbojet engine

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Highlights
- The newly created turbojet engine is described in detail.
- Gasturb 14 program was used for emission and thrust data.
- Performance and emission distributions of biogases were obtained.
- It has been observed that the use of biogas in a turbojet engine increases thrust.
- New fuel has been defined via GasTurb Details6.

You can cite this article as: Kumuk O. Effect of alternative biogas-methane fuels use on performance and emissions in turbojet engine. Int J Energy Studies 2024; 9(2): 239-253.

ABSTRACT

Researchers are trying to find alternative fuels to traditional fuels as traditional fuels are running out. This study is to predict turbojet gas turbine emission and performance using Methane and Biogas fuel blend for turbojet in Gasturb-14 program. Based on the physicochemical properties of each fuel, parameters were calculated for methane supplemented B1, B2 and B3 and pure methane fuel compositions. The heat of combustion for each blend was then obtained using GasTurb Details6 and the design points of the turbojet engine were determined. The program was run using biogas fuels to analyze performance and emission characteristics such as carbon monoxide, carbon dioxide, etc. In this study, the B3 blend was found to be the most effective Specific Fuel Consumption value with 32.22 g/kNs. It also produced lower emission rates for CO and CO_2 compared to B1 and B2 fuels. The first finding is that it is possible to burn an alternative biogas fuel to methane fuel. The results also show that biogas is very similar to methane in terms of temperature distributions in the combustion chamber due to its high methane content compared to other biogases.

Keywords: Biogas, Combustion, Emission, Gasturb software

1. INTRODUCTION

Fossil fuels such as coal, oil and gas face two major problems: limited availability and their contribution to global warming through CO2 emissions. To counter this, scientists are exploring alternative energy sources such as solar, wind, hydrogen and biomass. Among these alternatives, biogas is gaining traction due to its production from various organic sources such as wastewater, municipal waste and biomass gasification. Biogas mainly contains methane, a powerful energy source similar to natural gas, but depending on production methods, it also contains non-combustible components such as carbon dioxide and trace elements [1].

Performance studies for different parts of gas turbine engines are frequently found in the literature. Studies investigating the effects of different fuel types on combustion and engine performance have an important place in the literature [2,3]. Bhoi et al. [4] investigated the flame temperature and emission characteristics of a premixed burner. They showed that a swirl angle of 60° is suitable for maximum flame temperature, minimum pressure loss and minimum emission. Hosseini et al. [5] investigated the combustion characteristics of the flameless mode of biogas based on clean technology development strategies. The effects of preheating temperature and wall temperature, reaction zone and pollutant formation were observed and the effects of combustion and turbulence models on numerical results were discussed. Alabas et al. [6] explored the biogas/kerosene blend through numerical simulation, employing the oxygen enrichment technique. This method is recognized for its capacity to elevate flame temperature by leveraging the impact of biogas on lowering the temperature at the combustion chamber exit. Consequently, their findings revealed that oxygen enrichment led to heightened flame temperature and increased NO_X formation, while concurrently reducing CO emissions. Khan et al. [7] examined the effect of blending biohydrogen and biogas on diesel engine performance and emission characteristics. While Brake Thermal Efficiency (39.50%) increased, Brake Specific Fuel Consumption (156.73 g/kWh), Carbon Monoxide (0.39 g/kWh), Unburned Hydro Carbons (13.2 g/kWh) and Nitrogen Oxides (They found that it decreased by 108.02 g/kWh). Gaddigoudar et al. [8] examined the effect of biogas flow rate on the performance, combustion and emission characteristics of a dual-fuel diesel engine. They found that as the biogas flow rate increased, brake thermal efficiency (BTE), Peak pressure rise (PPR), Nitric oxide (NOx) and smoke emissions decreased, while Hydrocarbon (HC), Carbon monoxide (CO) and Ignition delay (ID) decreased. Numerical simulations and experimental studies were conducted by Jiao et al. [9] to investigate the effects on the combustion characteristics of the burner. The results revealed that the designed combustor showed good adaptability to simulated biogas with methane concentrations ranging from 55% to 80%.

In the study of Alabaş et al. [10], investigated the effects of augmenting a low-calorie biogas blend with hydrogen and oxygen on combustion stability and exhaust emissions using a premixed burner. The study revealed that biogas/hydrogen blends containing 20% and 30% H_2 showed the least combustion instability and pollutant emissions. Particularly, the mixture with 20% H_2 as the flame exhibited the lowest emissions and demonstrated resilience against acoustic distortions when combusted with 23% O_2 by volume.

Over the past two decades, a novel category of turbine engines known as microturbine engines has emerged, characterized by their high power to weight ratio, reliability, improved capability utilize intensity fuels [11,12]. Turbojet gas turbine fall of the category is generated through the momentium imparted by the gas outlet [13,14]. The utilization of microturbine engines has seen a rise across various sectors including general aviation, industries [15] and applications in UAV (unmanned aerial vehicles) . Enhancing engine performance can be achieved through the design or modification of microturbine engines; for instance, Virtual engine simulations offer a means to reduce the need for actual engine tests and attain consistent results, facilitating continuous analyses. This approach aids in lowering operational costs and maintenance of the engine [16]. Cost and risks are pivotal factors in the engine development process; hence, engine safety must be vigilantly monitored during operation. Dr. Joachim Kurzke has developed a computer-aided system named GasTurb to simulate turbojet engine capability. Furthermore, engine performance analysis, which assesses the specific performance of the engine across all flight conditions and throttle settings, holds significant importance [17]. Abu Talib et al. [18] investigated the performance of the CM4 turbojet engine using POME (palm oil methyl ester) and found B100 exhibited the blends fuel consumption compared to other mixture. Nanasaheb et al. [19], discovered that blending TPOME with diesel resulted in reduced CO emissions due to the oxygen content aiding complete combustion, thus lowering CO emissions. While some studies have explored the combustion of biogas or blended fuels, there remains a significant gap in understanding the combustion properties of biogas, including issues such as flame stability, spread, temperature, and emissions. This study focuses on assessing the combustion performance and emission characteristics of biogas containing various gas components under 61 kW thermal power and 1.2 excess air ratio. Each fuel type's characteristics are defined to input into GasTurb Details-6. Emission control for alternative fuels is facilitated through the program.

2. MATERIALS AND METHODS

2.1. Gasturb Program to Create New Fuel

In this study, due to the limited fuel options in the GasTurb-14 software, the properties of the biogas fuel had to be defined within the program. For this purpose, Applied Chemical Equilibrium (NASA CEA) [20] was used to determine the gas properties. The process followed to define these properties is shown schematically in Figure 1 and Figure 2, while the specific properties are detailed in Table 1. Three different types of biogas were selected: B1, B2 and B3. Table 2 shows the fuel characteristics. Initially, the program was run using the widely known Methane fuel and its performance was compared with different blends.

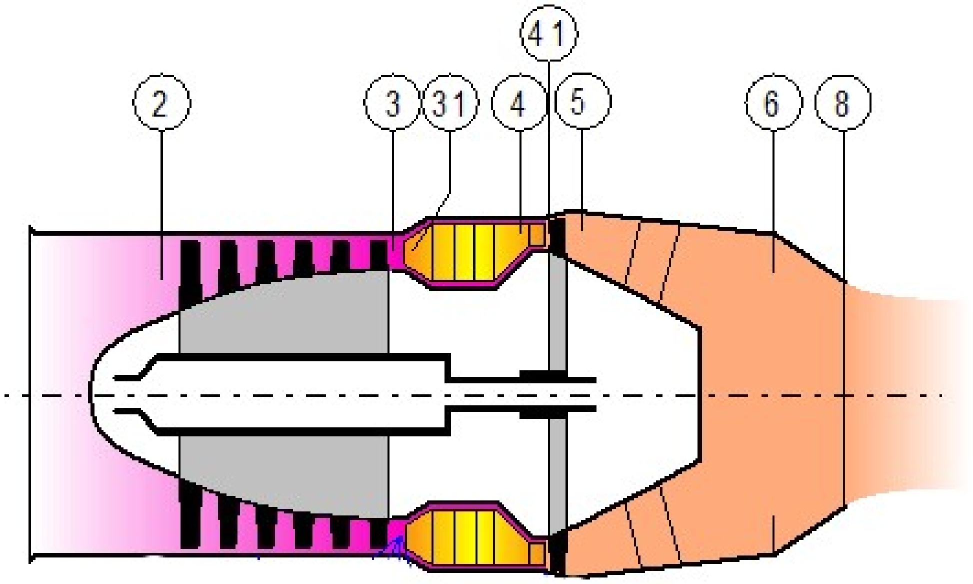

Figure 1. Diagram of the turbojet [21]

Table 1. Turbojet regions and areas [21]

Section	**Area**	**m^2**
2	LPC Inlet	0.52
3	HPC Exit	0.0744
31	Burner Inlet	0.06864
4	Burner Exit	0.06864
41	HPT Inlet	0.06864
5	LPT Exit	0.2292
6	Gas Exit	0.4394
8	Nozzle Throat	0.19075

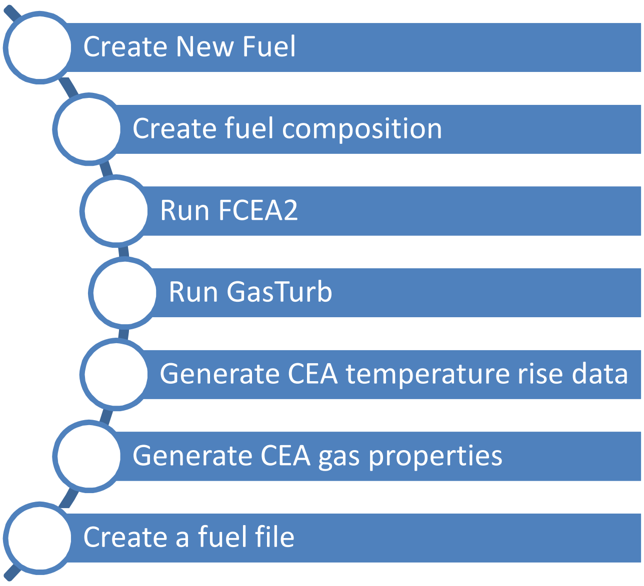

Figure 2. Simulation flowchart

Table 2. Biogas components [1]

	CH4	**CO2**	**N2**	**H2S**	**O2**	**Calorific Value (kcal/m3)**
Methane	100	-	-	-	-	8040,00
B1	55	43,1	1,53	10 ppm	0,3	4422,06
B2	60	38	1,5	0 ppm	0,5	4824,00
B3	65	33	1,3	0 ppm	0,7	5226,00

2.2. Engine Performance Analysis

To separately simulate the performance of the engine fired with Methane, B1, B2 and B3, the Gasturb--14 program was adapted to study the turbojet engine. GasTurb 14 simulation software was used to separately model and simulate the performance of a turbojet gas turbine engine fired with methane, B1, B2 and B3 fuels. A turbojet engine has similar or comparable power output, thrust, fuel flow, exhaust gas temperature, exhaust gas flow, etc. to the main engine. The turbine inlet temperature and other engine parameters are tuned until the desired engine performance parameters are achieved. Table 3 gives the general parameters and characteristics required for turbojet engine analysis. These parameters constitute the key performance indicators of the engine, which are indispensable for the examination of the pressurized and extended components of the engine, including the fan, compressor and turbine, in accordance with the established analytical framework. Gas turbine engines used industrially perform combustion at high excess air.

Table 3. Initial conditions

DESIGN PARAMETERS	
Parameter Name	**Parameter Value**
Suction Pressure Ratio	0,99
Internal Fan Pressure Rate	2,5
Outdoor Fan Pressure Rate	1,8
Compressor Internal Channel Pressure Rate	0,99
HP Compressor Pressure Rating	7
HP Compressor Pressure Rating	0,98
HP Reel Load Constant	0,99
LP reel Load Constant	1
Combustion Chamber Pressure Rate	0,97
Turbine Outlet Channel Pressure Ratio	0,98

3.RESULTS AND DISCUSSIONS

The GasTurb program is a simple and effective analysis software program designed to evaluate gas turbine performance and support preliminary design processes. This software has features that stand out for a task-oriented graphical interface and high-quality graphic outputs. GasTurb is intended for use in the gas turbine industry, aerospace industry, airframe manufacturing, airline industry, aircraft engine maintenance, power generation industry and other operations of gas turbines used in the air, land and sea.

Typically designed with specific design parameters, gas turbine engines often deviate from their ideal operating point during actual use. As a result, it is critical to analyze their performance over a range of operating conditions beyond their initial design specifications. Understanding how performance metrics change with throttle adjustments is particularly vital for evaluating the operational dynamics of an appropriately sized engine in different flight scenarios [22–24].

In this study, emissions and performance parameters were investigated, focusing on the HPC (High Pressure Compressor) pressure ratio at three different pressures: 1152, 2304 and 3457 kPa, while the LPC (Low Pressure Compressor) pressure ratio was kept constant. The range chosen is intended to cover a significant variation for the emission functions. Figure 3 shows the CO emissions resulting from combustion. It can be seen that all fuels exhibit similar CO emission patterns. Although CO emissions are minimal in all combustion modes, B1 fuel shows the highest production of 263.591x10-5 kg/s for 3457 kPa. Conversely, Methane fuel shows the lowest production during combustion with 21,938x10-5 kg/s for 1152 kPa. The figure clearly shows that increasing the HPC outlet pressure leads to an increase in CO production in the turbojet engine. The CO2 emissions from the turbojet engine are shown in Figure 4. The emissions remain consistent for the same operating parameters. Higher pressure values result in relatively consistent CO2 production rates. In particular, B1 combustion exhibits the highest CO2 emissions, peaking at 14.21 kg/s for 3457 kPa, while methane combustion shows the lowest CO2 emissions at 1.59 kg/s for 1152 kPa.

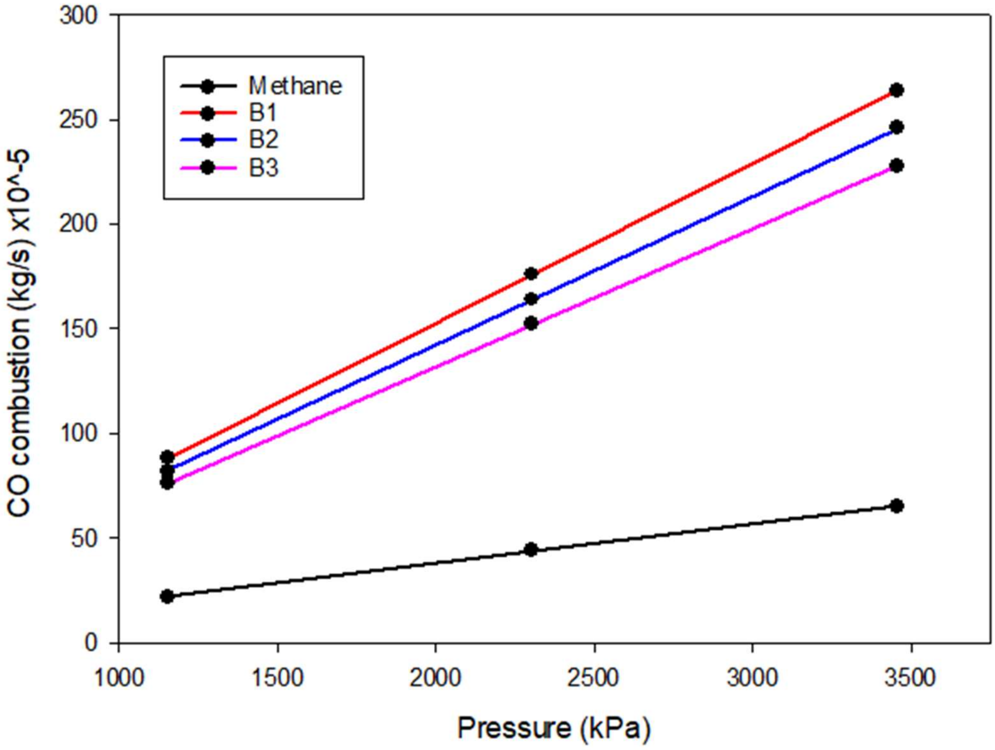

Figure 3. CO emissions from different fuel combustion

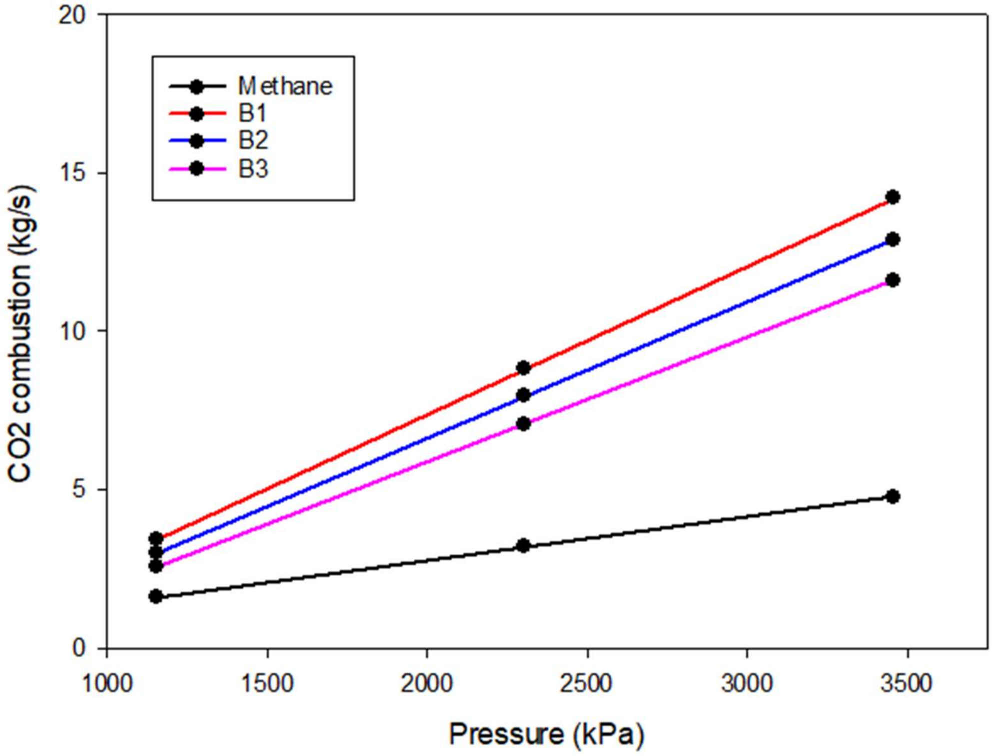

Figure 4. CO_2 emissions from different fuel combustion

Figure 5 shows emissions of unburned hydrocarbons, a parameter of great importance due to its contribution to photochemical smog and its role in the greenhouse effect through absorption of infrared radiation. The magnitude of this impact can vary depending on the type of fuel used. The decreasing trends in unburned hydrocarbon emissions indicate that a significant proportion of fuels are burned efficiently.

Although the emission values are close to each other, methane fuel combustion shows the lowest levels of unburned hydrocarbons, while B1 combustion shows the highest values. The lowest production of unburned hydrocarbons among all fuels is observed during Methane combustion with a minimum of 1.80x10-9 at 1152 kPa, while the maximum production occurs during B1 combustion with 21.64x10-9 at 3457 kPa.

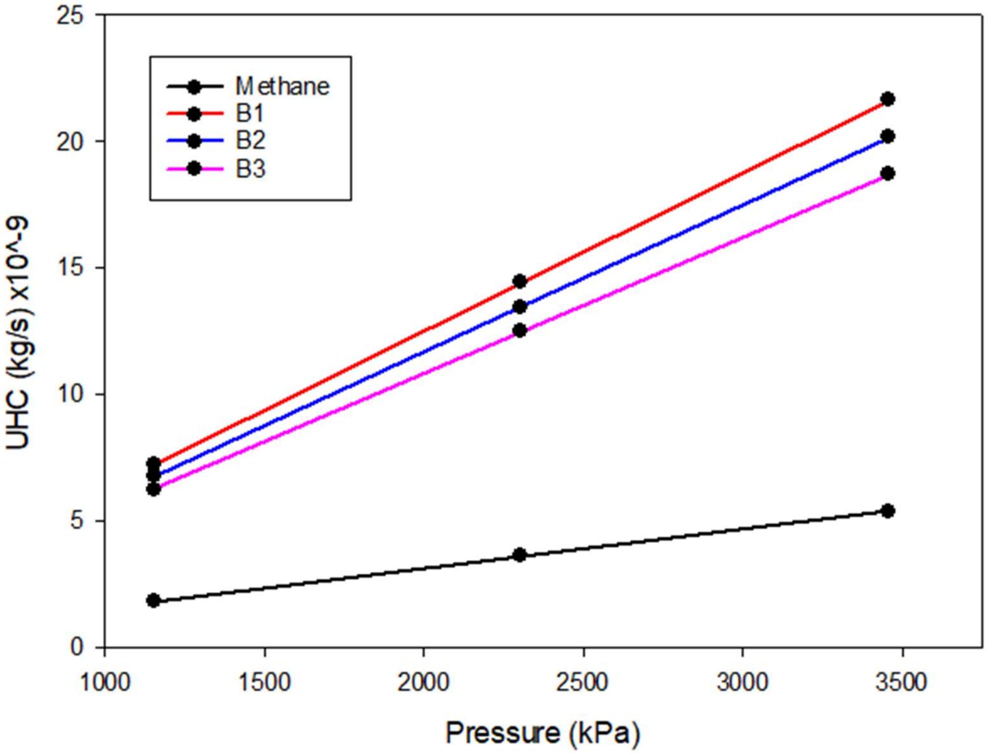

Figure 5. Unburned hydrocarbon emissions from different fuel combustion

Figure 6 and Figure 7 show the operating conditions of the off-design performance showing the calculated net thrust and SFC (Specific Fuel Consumption) values. These performance metrics were obtained from off-design performance calculations performed in GasTurb14 using the program mentioned above. The study of trends in parameters such as net thrust and SFC, which are crucial in determining engine performance, is crucial in providing insights into engine development and application. In this analysis, the thermodynamic process is assumed to be adiabatic and pneumatic losses are not considered. Pressure ratio and turbine inlet temperature directly affect thrust levels and engine efficiency.

Figure 6 shows the changes in performance parameters under normal conditions where the rotational speed is at maximum and the pressure is set to 3457 kPa. The net thrust shows a rapid increase with increasing pressure. As shown in Figure 6, the highest thrust is 64.21 kN for B1 fuel, while the lowest thrust is 26.9 kN for Methane fuel. In particular, the thrusts for fuels B1, B2 and B3 show minimal variability.

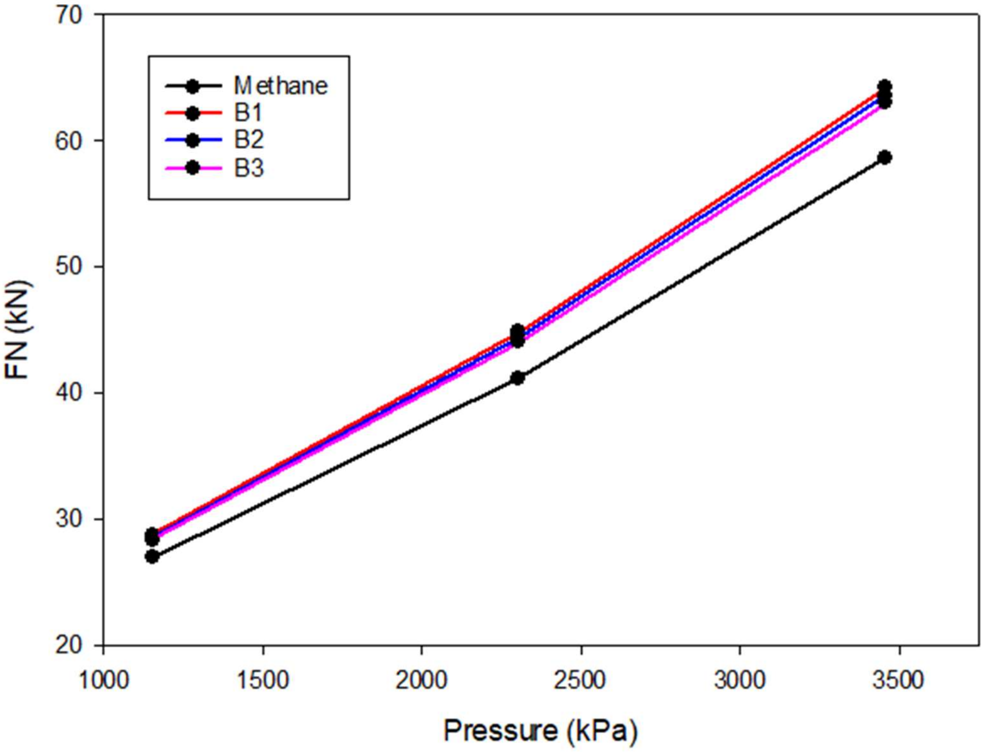

Figure 6. Net thrust from different fuel combustion

An increase of 7.44% was observed in the total thrust value of methane blended B1, B2 and B3 fuels under a total pressure of 1152 kPa. Figure 6 also shows an increase of 8.44% under a pressure of 3457 kPa. This increase can be attributed to the increase in the mass of fuel initially entering the combustion chamber. In other words, a higher increase in thrust indicates that the engine is running more efficiently. In order to understand the exact reason for the increase in thrust, the Low Pressure Turbine outlet temperatures need to be examined and also the exergy and total pressure values need to be analyzed.

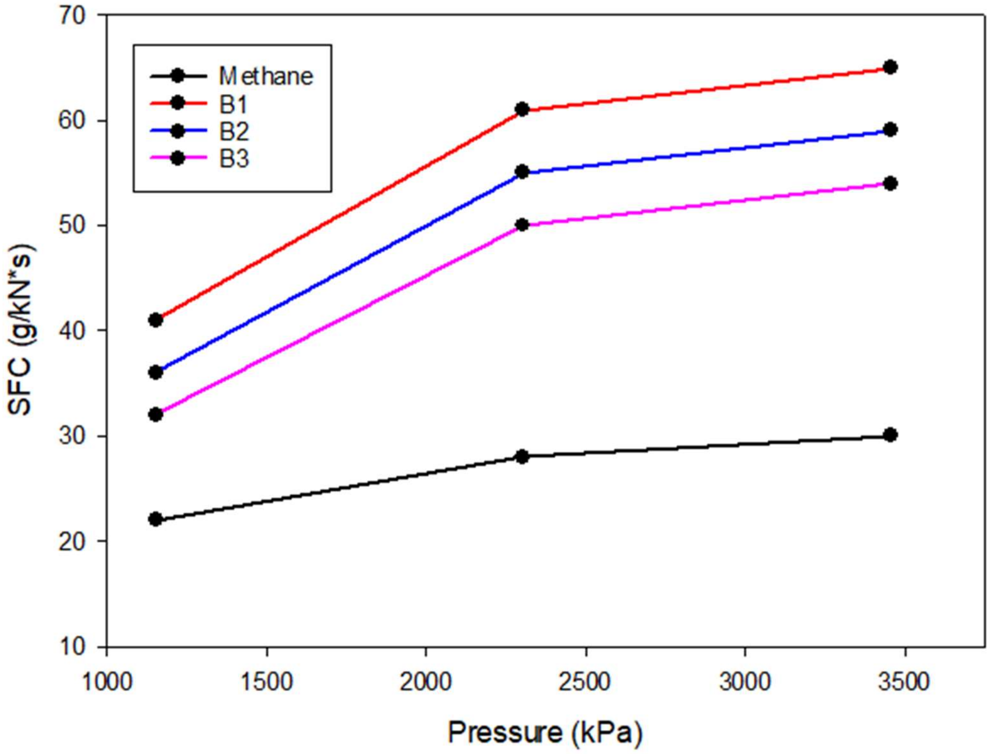

Figure 7. Specific fuel consumption from different fuel combustion

Figure 7 illustrates the effect of pressure variations on the specific fuel consumption (SFC) for Methane, B1, B2, and B3 fuels. It is observed that the SFC of all fuels increases as the pressure is increased. The lowest SFC values for Methane, B1, B2, and B3 fuels are 22.01 (g/kN.s), 40.94 (g/kN.s), 36.59 (g/kN.s), and 32.22 (g/kN.s) respectively. The results can be explained by the higher specific fuel consumption of B1, B2, and B3 fuels compared to Methane fuel, which is attributed to their lower calorific value. Adjusting Fuel Flow to Compensate for Engine Temperature Variation in Alternative Fuel Combustion.

4. CONCLUSION

Recognition of the dwindling availability of conventional fuels has prompted many researchers to explore alternative options, with biodiesel emerging as a promising alternative due to its renewable performance. This study aims to identify alternative biogas fuels suitable for GasTurb-14 software and assess their impact on gas turbine emission and performance properties such as carbonmonoxide, carbondioxide etc.

Three types of biogas mixtures, namely B1, B2, and B3, are investigated and primarily compared with the results obtained using Methane fuel. It has been concluded that biogas fuels and methane fuel consumption are quite close and can be an alternative. In contrast, specific fuel consumption (SFC) for B1, B2 and B3 fuel mixtures were close to each other. An increase of 7.44% was observed in the total thrust value of methane blended B1, B2 and B3 fuels under a total pressure of 1152 kPa. Additionally, it can be seen in Figure 6 that there is an increase of 8.44% under 3457 kPa pressure. The B3 mixture was found to have the most effective SFC value of 32.22 g/kNs.

The methodology introduced holds significance for individuals engaged in engine design, environmental science, and aviation practice alike. Its applicability extends to various sectors, making it valuable for understanding the interplay between fuel choices, engine performance, and environmental impact.

In future studies, the authors plan to expand the application of this methodology to different types of aircraft engines, encompassing both jet and electric propulsion systems. This broader scope will allow for a more comprehensive understanding of the implications of alternative fuels across various aviation technologies, facilitating informed decision-making in the pursuit of sustainable aviation solutions.

NOMENCLATURE

CO	Carbon monoxide
CO_2	Carbon Dioxide
NO_x	Nitrogen Oxide
BTE	Brake Thermal Efficiency
PPR	Peak Pressure Rise
HC	Hydrocarbon
ID	Ignition Delay
H_2	Hydrogen
O_2	Oxygen
CH_4	Methane
N_2	Nitrogen
UAV	Unmanned Aerial Vehicles
HP	High Pressure
LP	Low Pressure
HPC	High Pressure Compressor
LPC	Low Pressure Compressor

ACKNOWLEDGMENT

The author would like to thank GasTurb GmbH. I would also like to thank CEO: Daniel Weintraub, M.Sc., for providing a trial version of his program and a provisional license for academic study.

DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Osman Kumuk: Performed numerical analysis and analyse the results. Wrote the manuscript.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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