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Impact of Petrol-Ethanol Blending Ratios on the Performance and Combustion Efficiency of Spark Ignition Engines

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Abstract

Alternative fuels are expected to play an important role in future developments of spark ignition engines, the main reason being the need to reduce dependence on fossil fuels due to its harmful environmental impact. This study aims to analyse the performance of gasoline-ethanol fuel blends on a four stroke spark ignition engine test bed and compare the performance with that of pure gasoline. Different blend ratios (by volume); E3 (3% ethanol and 97% gasoline), E6 (6% ethanol and 94% gasoline), E9 (9% ethanol and 91% gasoline) and E12 (12% ethanol and 88% gasoline) were studied in this work. The test was conducted on a TQ small engine test bed located in the University of Benin. Engine performance calculations were used in determining the brake power, torque, specific fuel consumption and efficiencies of the engine when the different fuel blends were used. The various results obtained were compared to that of pure gasoline, E0 (0% ethanol and 100% gasoline) the base/control fuel. The results obtained showed noticeable increase in the break power, torque and thermal efficiency compared to that of pure gasoline. However, there was also a noticeable slight increase in the specific fuel consumption of the engine. Finally, of all the tested samples, E12 blend gave a better overall performance when compared to the control fuel

1. Introduction

The escalating global population and rapid industrialization have driven an unprecedented surge in energy demand, particularly within industrial and domestic sectors [1-3]. This demand presents a pressing challenge as fossil fuels, the primary energy source, grapple with dual crises: dwindling reserves and the environmental consequences of combustion.

The Malthusian theory underscores this challenge, suggesting that population growth outpaces the linear growth of resources, thereby widening the energy gap [4]. Moreover, the combustion of fossil fuels releases harmful emissions such as carbon monoxide (CO), nitrogen oxides (NOx), and particulate matter, which not only degrade air quality but also exacerbate global environmental issues and public health risks [5-8]. Addressing these challenges necessitates the exploration of sustainable and cleaner energy alternatives.

One promising strategy involves the blending of oxygenates, such as alcohols (e.g., ethanol, methanol, propanol, butanol), with gasoline. Alcohols possess inherent advantages: their higher oxygen content improves combustion efficiency, their elevated octane numbers enhance engine performance, and their significant latent heat of vaporization cools the combustion charge, thereby reducing NOx emissions [9]. These characteristics make alcohol-gasoline blends a compelling alternative for cleaner and more efficient energy use.

Extensive research has demonstrated the potential of alcohol-gasoline blends to improve engine performance and reduce emissions. For instance, Kothare et al. [10] examined ethanol, butanol, propanol, and pentanol blends in a single-cylinder spark ignition (SI) engine and found that a 10% ethanol blend (E10) optimized brake thermal efficiency while reducing brake-specific fuel consumption compared to pure gasoline. In Brazil, flexible-fuel engines enable vehicles to efficiently utilize high ethanol blends, with over 20% of vehicles operating on pure ethanol. Similarly, Shanmugansudaram et al. [11] reported that camphor-ethanol-gasoline blends reduced specific fuel consumption, lowered exhaust emissions, and enhanced both thermal and volumetric efficiency.

Further studies affirm these benefits. Altun et al. [12] observed a 15% reduction in hydrocarbon (HC) emissions using 10% ethanol blends, while methanol blends achieved up to a 10.6% reduction in CO emissions. Mortadha and Mudhaffar [13] demonstrated that ethanol blends increased octane numbers, reduced exhaust emissions, and improved thermal efficiency, with a 40% ethanol blend enhancing efficiency by 25.8%. Additionally, Vertin et al. [14] noted significant emission reductions with 15–20% ethanol blends, and Schifter et al. [15] found that blends containing 17–24% ethanol reduced HC and CO emissions with negligible increases in NOx emissions. These findings collectively highlight ethanol's potential as a sustainable gasoline additive that delivers both environmental and performance advantages.

Building on this foundation, the present study investigates the performance of petrol-ethanol blends (0–12% ethanol by volume) in a four-stroke spark ignition (SI) engine. By comparing these blends to pure gasoline (E0), this research aims to provide valuable insights into the optimal blending ratio for enhanced engine performance and reduced emissions.

2. Materials and Methods

2.1 Materials

The experiments were conducted using a TQ Small Engine Test Bed housed in the Mechanical Engineering Laboratory at the University of Benin. This bench-mounted setup integrates a hydraulic dynamometer to simulate variable load conditions and measure engine performance metrics.

2.1.1 Test Bed Configuration and Hydraulic Dynamometer

The hydraulic dynamometer is a key component of the test setup, utilizing water flow to provide a resistive load to the engine. The dynamometer’s operation is based on the water flow rate and the water level within its casing:

- Water Flow Control: A precision needle valve regulates the flow rate, offering fine-tuned adjustments to the load. Water enters the dynamometer through a valve at the top and exits via a bottom drain.
- Load Mechanism: As the engine shaft rotates, the ribs on the casing and rotor agitate the water, generating resistive torque. This torque is measured by a load cell connected to the dynamometer.
- Load Variation: By increasing the water flow rate, the water level rises, inducing greater resistance. This feature enabled testing under varying simulated load conditions to assess the performance of different fuel blends effectively.

2.1.2 Engine Specifications and Operation

The test engine features a single-cylinder, four-stroke spark ignition (SI) engine with a cross-flow architecture:

- Fuel-Air Path: The air-fuel mixture enters through one side of the cylinder head, while exhaust gases exit from the opposite side.
- Cooling Mechanism: Fins around the flywheel and ducting direct airflow to maintain consistent cooling as the engine operates. The flywheel’s rotation drives this airflow, ensuring stable thermal conditions during prolonged tests.
- Startup Procedure: Engine ignition is achieved manually using a starter handle and rope wound around a pulley on the flywheel.

2.1.3 Data Acquisition and Measurement

The test bed is equipped with a Versatile Data Acquisition System (VDAS 5.2.0) connected to a computer, enabling real-time monitoring and data collection. The TQ test bed's robust configuration allows for controlled simulation of real-world engine loads, ensuring that experimental results are both reliable and representative. The hydraulic dynamometer's precise load control and the integration of VDAS enhanced the accuracy of performance evaluation and emissions analysis. The system measured the following performance and combustion parameters:

- Thermal Efficiency: Assessed to understand energy conversion rates of the different fuel blends.
- Torque and Power Output: Measured to evaluate the engine's mechanical performance under various load conditions.
- Specific Fuel Consumption (SFC): Analyzed to determine the efficiency of the engine in utilizing the fuel blends.
- Calorific Value and Heat of Combustion: Key indicators of the energy potential of the tested fuels.
- Exhaust Emissions: Monitored to assess environmental impacts, including CO, HC, and NOx levels.

The VDAS provided high-resolution data, ensuring accuracy in measuring critical metrics under dynamic operating conditions.

2..2 Methods

2.2.1 Experimental Procedure Fuel Preparation and Specifications

Five fuel blends were prepared for this study, with varying ethanol-to-gasoline ratios:

- E0: 0% ethanol, 100% gasoline (reference fuel).
- E3: 3% ethanol, 97% gasoline.
- E6: 6% ethanol, 94% gasoline.
- E9: 9% ethanol, 91% gasoline.
- E12: 12% ethanol, 88% gasoline.

The base gasoline was sourced from a local fuel station, while ethanol with a purity of 99% was obtained from a certified chemical supplier. To ensure consistent quality, the ethanol was analyzed for impurities before blending. The calorific values of ethanol and gasoline were assumed to be 26.9 MJ/kg and 44.0 MJ/kg, respectively, based on standard references.
Each fuel blend was prepared volumetrically using precise graduated cylinders to maintain accuracy. The mixtures were agitated thoroughly to ensure homogeneity and were stored in sealed containers to prevent evaporation before testing.

- Experimental Procedure
- Initial Setup and Calibration

2.2.1 Experimental Procedure for Test Bed

The TQ Small Engine Test Bed was calibrated prior to the experiment to ensure accurate torque and speed measurements. The test bed includes a hydraulic dynamometer to simulate load conditions and the Versatile Data Acquisition System (VDAS 5.2.0) for real-time monitoring of performance parameters. All sensors, including those for fuel flow and exhaust emissions, were validated for proper functioning before commencing the tests.

2.2.3 Testing Protocol for Fuel Blends

1. Starting with the Reference Fuel (E0):
    - o The engine was primed with E0, and the needle valve controlling the hydraulic dynamometer load was initially closed.
    - o The engine was started manually using a starter handle and rope. To ensure consistent operating conditions, the engine was allowed to run for three minutes without load to stabilize.
    - o Performance parameters—such as torque, brake power, fuel flow rate, brake thermal efficiency (BTE), specific fuel consumption (SFC), and heat of combustion—were measured at steady-state conditions using the VDAS interface.
2. Introducing Load:
    - o The needle valve was gradually opened to introduce load, incrementally reducing the engine speed.
    - o At each speed, the engine was allowed to stabilize for an additional three minutes to ensure reliable readings. Performance data were recorded across a range of engine speeds to assess the fuel's performance under varying load conditions.
3. Switching Fuel Blends:
    - o After completing the test with E0, the fuel line was drained completely, and the system was purged to avoid contamination of subsequent blends.
    - o The engine was then fed with the next blend (E3), and the process was repeated under identical conditions.

This procedure was systematically carried out for all five blends (E0, E3, E6, E9, and E12), ensuring consistency in operating conditions and data collection for comparative analysis.

2.3 Data Collection and Analysis

Performance metrics and emission data were recorded using the VDAS software, providing high-resolution outputs for parameters such as:

3 Brake Torque and Power Output: To evaluate mechanical efficiency.
4 Specific Fuel Consumption (SFC): To measure fuel economy across blends.
5 Brake Thermal Efficiency (BTE): To assess the energy conversion efficiency.
6 Calorific Value and Heat of Combustion: To gauge the energy potential of each blend.
7 Exhaust Emissions: Including CO, NOx, and unburned hydrocarbons, providing insights into the environmental impact of each blend.

All collected data were processed and analyzed using Microsoft Excel. Comparative plots were generated for key parameters, including torque, power, and fuel efficiency, under various speeds and loads. The differences in performance and emissions among the fuel blends were statistically evaluated to identify trends and optimal blending ratios.

2.4 Experimental Controls and Consistency

To maintain experimental integrity:

- The engine was operated under steady-state conditions during all measurements.
- Each test was repeated three times for each blend, and the average values were used for analysis to minimize errors.

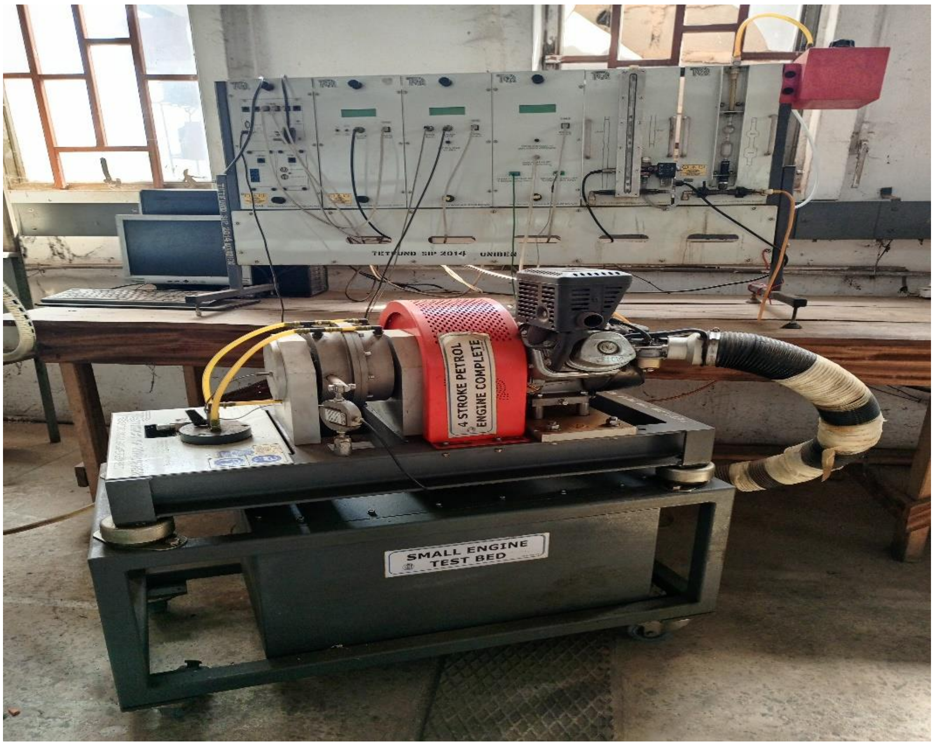

FIG 1: Single Cylinder Small Engine Test Bed

The specifications of the test bed used in conducting the experiment is given in Table 1.

Table 1: TEST BED SPECIFICATION

ITEM	SPECIFICATION
Dimensions (when fitted to base plate)	Width 500mm height, 430 mm Depth
Net weight (with base plate)	22kg
Fuel type	Gasoline & ethanol mix of 90% unleaded gasoline and up to 10% ethyl alcohol
Exhaust tank	Red – painted steel vent and filler cap
Exhaust outlet	Nominally 1” BSP
Ignition system	Electric
Absolute maximum power	5.2KW (7 hp) at 3600 rev/min
Net power	4.5kW at 3600 rev/min 2.2 kW at 1800 rev/min
Bore	70mm
Stroke/crank radius	54 mm/27 mm
Connecting rod length	84mm
Engine capacity	208 cm^3
Compression ratio	8:5:1
Oil type*	SAE30 or Multigrade 10W-30
Oil capacity	0.6 litre

3. Results and Discussion

3.1 Effect Of Petrol-Ethanol Blends On Engine Power

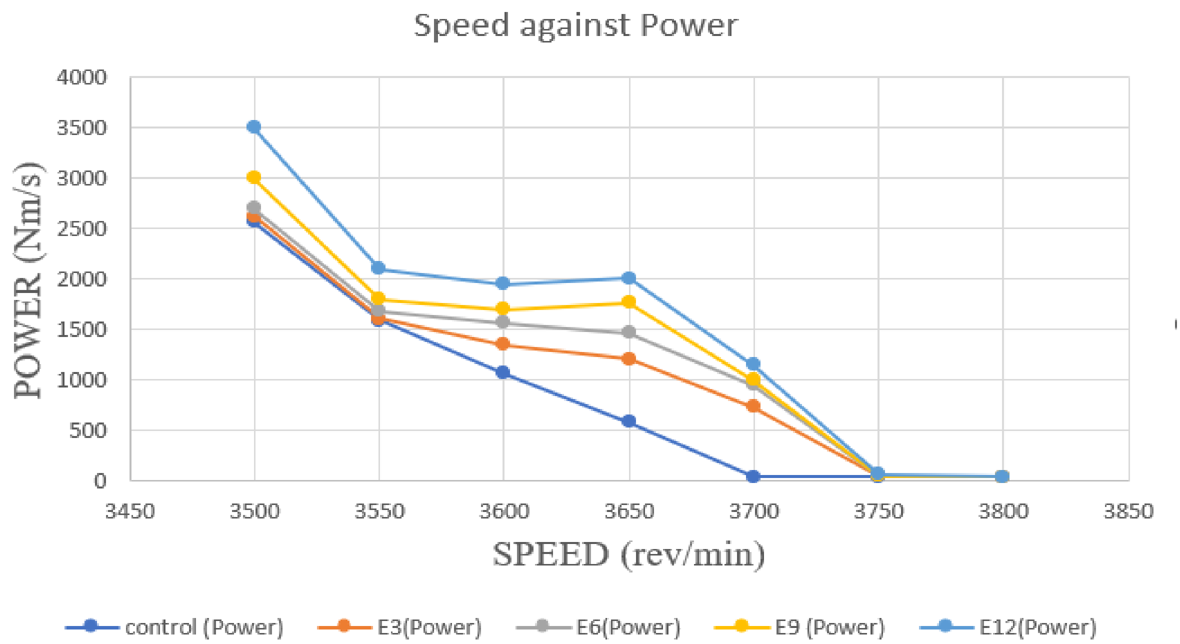

Fig2: Graph of Engine Power output against Speed

Figure 2 above shows the relationship between speed and power from various blends, there is a linear decrease in the power of the unblended fuel as the speed increases, while the blended fuels also experienced linear decrease from a speed of 3500rpm to 3550rpm there after the power was fairly constant up till 3650rpm before experiencing another linear decrease up till 3750rpm. The highest engine brake power was 3500W, recorded by E12 at a speed of 3500rev/min. The E0 sample served as the baseline for comparison. As expected, it exhibited higher power output due to pure gasoline's greater calorific value. However, this blend also likely produced higher emissions compared to ethanol-blended fuels due to the absence of oxygenated compounds in its molecular structure

3.2 Effect Of Petrol-Ethanol Blends On Engine Torque

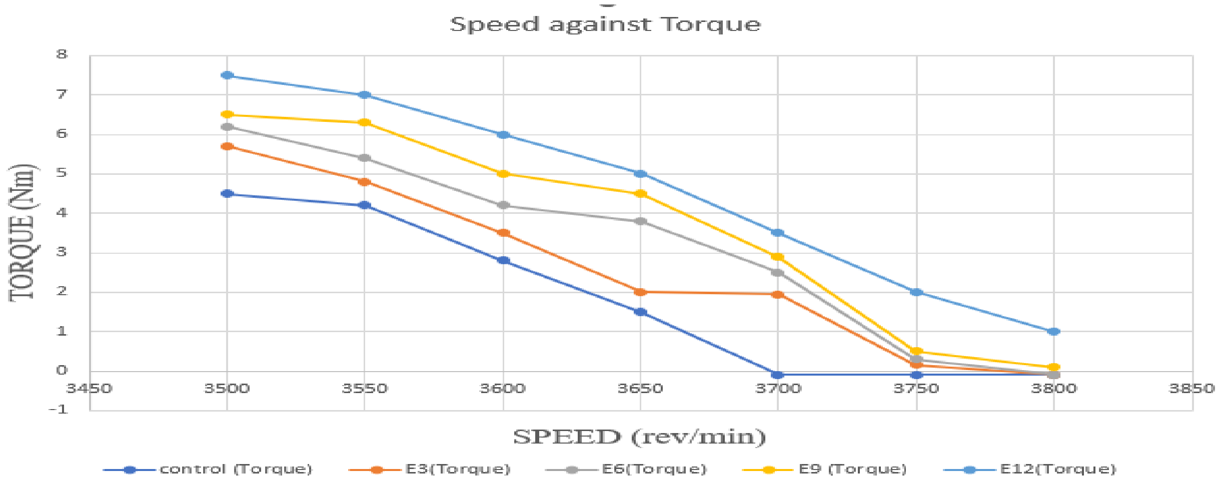

Fig 3: Graph of Engine Torque against Speed

Figure 3 shows a linear reduction in the engine torque as the engine speed increases for all tested samples. Ethanol's lower calorific value may reduce the energy per unit mass and hence the torque, Since the rated output power of a motor is a fixed value, speed and torque are inversely related.

$P=2\pi NT$ Where P=power(Nm/s), N=speed(rev/s)and T=torque(N.m)

As the output speed increases, the available output torque decreases with the highest torque being 7.8 Nm recorded by E12 while running at the lowest speed and E0 producing the lowest torque.

3.3 Effect of Petrol Blends on Engine Thermal Efficiency

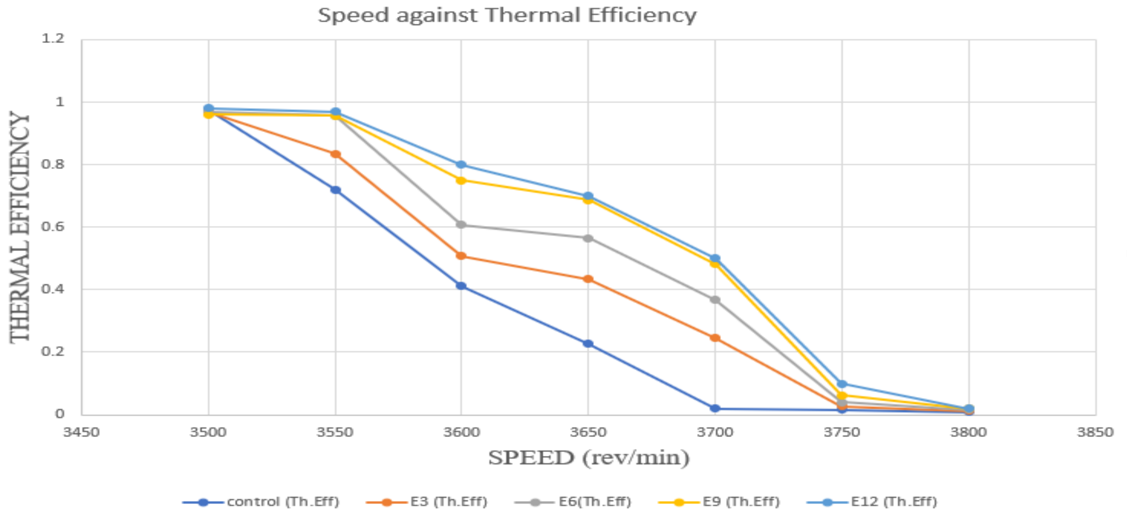

Fig 4: Effect of Petrol Blends on Engine Thermal Efficiency

The thermal efficiency of a heat engine is the amount of thermal energy that is being converted into useful work. The thermal efficiency of different blending percentages at different engine speeds were recorded and shown via fig 3. Ethanol blends typically increase thermal efficiency due to improved combustion as they balance ethanol's oxygenation benefits with adequate energy content from gasoline. E12 had the highest efficiency at the varying speeds. This is due to an improvement in the fuel combustion by a high burning flame rate with a reduced heat loss and a high octane rating. Since the Hydro Carbon ratio of ethanol is higher than that of gasoline, there are more oxygen molecules to completely burn the carbon during the thermal energy conversion process. As noticed from the graph, as the speed increases, the thermal efficiency reduces simultaneously; this is because with an increase in engine load, there is a reduction in the engine speed therefore more energy is needed to overcome the load. As the load is gradually reduced, the speed gradually increases leading to a decrease in the amount of thermal energy needed to overcome the load.

3.4 Effect of Petrol-Ethanol Blends on Engine SFC

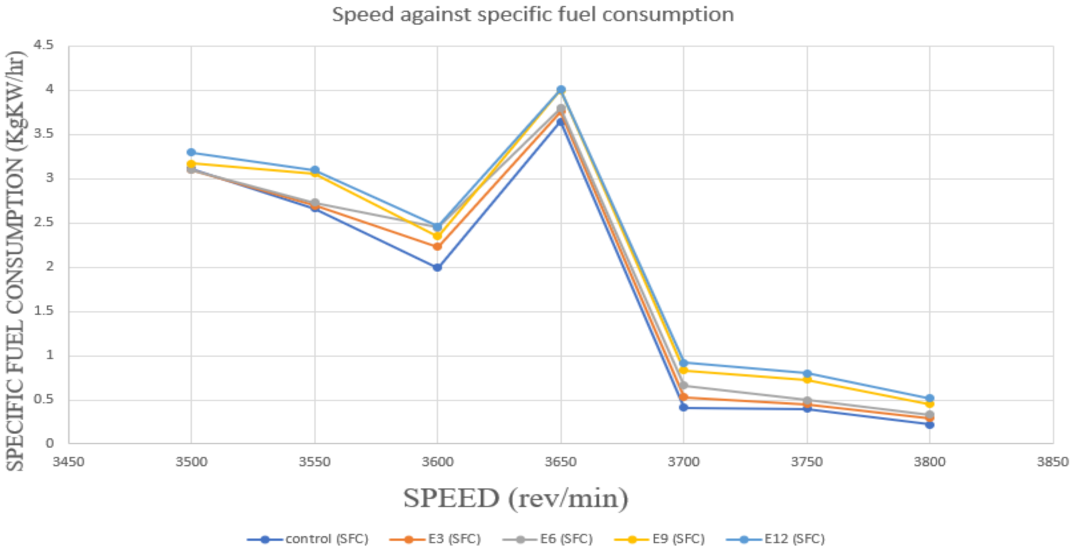

Fig 5: Graph of Petrol blends against Specific fuel consumption

Higher ethanol blends result in increased SFC because of ethanol's lower calorific value, requiring more fuel to generate the same energy output. This is because the heating value of ethanol is lower than that of gasoline. Therefore, more amount of fuel will be needed to be burnt to archive a desired set power, hence, the reason for the increase in specific fuel consumption as the blending percentage increases with E12 consuming more fuel at all tested speeds and E0 consuming the least fuel with the maximum fuel consumed by all samples at a speed of 3650rpm.

4. Conclusion

This work investigated the performance of gasohol on spark ignition engines using a blend percentage from the range of 0% to 12% by volume of ethanol to gasoline and comparing the performance of the various blends with the control fuel (E0). This work investigated the power, torque, specific fuel consumption and thermal efficiency of the various blends on a single cylinder four stroke petrol TQ small engine test bed. The blends were examined at various engine speeds and the following were drawn from the observations;
As the percentage of ethanol (by volume) increases, the power, torque, specific fuel consumption and thermal efficiency at all operating speeds also increases without any modification of the engine with a blend of 12% ethanol and 88% gasoline producing the highest power, torque, specific fuel consumption and thermal efficiency at all operating speed.

The specific fuel consumption increases as the blended volume increases to compensate for the lower heating value of ethanol. E12 produced the highest SFC due to lesser percentage of gasoline. E12 is a more desirable blend from all tested samples due to its increase in engine power, torque and thermal efficiency without any modification of the test bed.

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