A study on the performance analysis of bioethanol produced from sugarcane molasses in SI engine

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Abstract. Recently with ethanol being a renewable, bio-based and ecofriendly, it is projected to be the best replacement for petrol as a fuel in SI engines. Ethanol is derived mainly from sugarcane, cassava, corn and other waste biomass materials. These materials are rich in calories and could be utilized either as complements or as alternatives for conventional fuel sources. This paper aims to experimentally determine the properties of ethanol/gasoline blends and tests its performances in an SI engine. The E10, E20 and E30 ethanol-gasoline blends were studied and compared to gasoline fuel. It was found that the performance of the engine using bioethanol blends was almost comparable to that of pure gasoline, especially at lower ethanol content blends. Yet, increasing the ethanol content only gives adverse effects to the overall engine performance, resulting in 8.86% power loss at 2000 rpm for E20 and 8.18% for E30 compared to E0. Suggestively, with more research and experiments, bioethanol-fuel blends can replace pure gasoline fuels easily and with many added benefits on the same or slightly modified engines.

1. Introduction

Nowadays, most of the fuels used in transportation are in a liquid form due to its ease of storage, and the use of gaseous and solid fuels has gradually declined [1, 2]. There exist two different types of fuels: fuels from fossil resources and biofuels produced from renewable energy sources [3-5]. There is a high demand for alternatives or renewable form of fuels today due to the increase in consumption of motor fuels and the reduction of global oil reserves [6, 7]. Furthermore, global warming has also contributed to the sharp rise in the demand for renewable sources of energy [8, 9]. Bioethanol is currently regarded as the most suitable fuel to substitute petroleum-based fuels in automobiles.

It was reported that the use of biofuels depends on the availability and sustainability of biomass [10]. Another determinant in biofuel use is the biofuel policy, as it can greatly contribute to the successful penetration of the biofuel market. The largest amount of biofuel is produced from plant feedstock sources which must be planted, harvested and processed into biofuel. Other biofuel sources are wastes and animal excrements. From the point of view of recent researches, it is greatly accounted that bioethanol is one of the most promising type of biofuels [11]. Currently, however, most of the ethanol produced globally is used for purposes other than transport-related applications. Nonetheless, as the oil prices
continue to rise and more countries adopt policies which place significant favour towards the use of biofuels, ethanol based fuel is being widely regarded as a very viable alternative [12, 13].

In Mauritius, sugar industry is considered as one of the dominant industries. For decades, it was the main industry in the particular nation, producing sugars to be supplied in various European countries. In recent years, due to increasing competition and diversification of the economy by the government, the sugar industry has been in decline. However, most parts of the country still consist of sugarcane plantations. Although the sugar industry has been using bagasse, a by-product of sugarcane, to produce electricity; and molasses, another by-product, to produce ethanol, there has been little to no attempt to use the ethanol in the transport sector as fuel – especially since Mauritius imports all its oil supply. Mauritius generates 43.5% of its electricity from bagasse, so far, the production of ethanol as a fuel has not been tried [14]. The objective of this study is, therefore, to investigate the performance of bioethanol blends in the SI engine. This would help examine the suitability of bioethanol blends as an alternative, renewable source of fuel for the transport sector of Mauritius.

2. Methodology

2.1. Sample preparation

The pure ethanol (>99% concentration) sample was procured from RCI Labscan Limited. The physical and chemical properties of the ethanol are listed in Table 1. The Petron Blaze 95 was chosen as the conventional fuel used in the mixing process. It is a regular gasoline which has been formulated using latest additive technology to provide optimum engine performance. It contains additives which keep the engine’s fuel injectors and intake valves clean and efficient in the long run. It also reduces engine friction and enhances power and effectiveness. Additional benefits given by the particular fuel includes optimum power and acceleration, improved fuel economy and better engine protection. The reason for choosing this particular petrol type is because it can be used for both conventional and high-performance gasoline engine [16]. The mixing process consisted simply of pouring and mixing the gasoline and the ethanol in specific proportions in a container. Since both solutions are volatile and flammable, the mixing process was carried out in the chemistry laboratory of INTI International University, Nilai.

| Table 1. Properties of ethanol Sample from RCI Labscan Limited [15]. |
| --- |
| Appearance: Form Colour | Liquid Colourless |
| Odour | Alcohol-like |
| pH | 7.0 at 20 °C |
| Melting Point | -114.5 °C |
| Boiling Point | 78.3 °C at 1013 hPa |
| Vapor Pressure | 59 hPa at 20 °C |
| Density | 0.790 g/ml at 20 °C |
| Water Solubility | Soluble at 20 °C |
| Viscosity | 1.2 mPa.s at 20 °C |

Four samples were prepared, namely one sample of 7.5 liters of pure gasoline, one sample of 7.5 liters consisting of 750 ml of ethanol and 6750 ml of gasoline, one sample of 7.5 liters consisting of 1500 ml of ethanol and 6000 ml of gasoline, and another sample of 7.5 liters consisting of 2250 ml of ethanol and 5250 ml of gasoline. The pure gasoline sample is the reference or control fuel for the tests. During the mixing process, no distinct phase separation was observed in the mixtures. Figure 1 shows the sample of mixing gasoline and ethanol.
Each of these samples were further divided into four different containers, namely four containers containing 6.5 liters of each sample, to be used for SI engine testing; 4 containers containing 200ml of gasoline, E10, E20 and E30 respectively for Properties Tests, and 12 containers with different samples for observation tests. Table 2 shows fuels samples and their abbreviations.

Table 2. Fuel samples and their abbreviations.

| No. | Fuel                                      | Abbreviation |
|-----|-------------------------------------------|--------------|
| 1   | 100% Gasoline (Reference fuel)            | Gasoline/ E0 |
| 2   | 90% Gasoline + 10% ethanol                | E10          |
| 3   | 80% Gasoline + 20% ethanol                | E20          |
| 4   | 70% Gasoline + 30% ethanol                | E30          |

2.2. Properties test

One batch of 4 containers containing 200 ml of Gasoline, E10, E20 and E30 respectively, were sent to the chemical engineering laboratory of the Faculty of Chemical Engineering, Universiti Teknologi MARA (UiTM) to carry out properties testing. The kinematic viscosity test was carried out using a Cannon-Fenske opaque viscometer depicted in figure 2. The calorific value test was carried out using a Bomb Calorimeter IKA C5000 shown in figure 3.

The density of each sample was determined using the formula: Density = mass/volume. The volume of each sample was 200 ml. The mass of an empty beaker was weighed on an electronic scale, then one sample, for example E10, was poured into the same beaker and weighed. The mass of 200 ml E10 sample was found to be [(mass of beaker + E10 sample) – (mass of empty beaker)]. This process was repeated using the gasoline, E20 and E30 samples respectively and their densities were calculated. The room temperature was kept constant at 30 °C.
2.3. SI engine testing
The engine used for this experiment was located at the Mechanical Engineering Laboratory, Faculty of Engineering, Universiti Putra Malaysia (UPM). Figure 4 shows the schematic diagram of the engine. Its specification is depicted in Table 3. The engine was connected to a water brake dynamometer and an exhaust gas analyser which generally shows CO and Hydrocarbon emissions. The aim of this test was to use the different blends of ethanol and gasoline in the same engine and carry out a performance analysis. A test run was carried out for 20 minutes to warm up the engine. The petrol tank was then completely drained. 100% gasoline sample (E0) was fed into the engine and the Power and Torque at different speeds (1200-3200 rpm) are noted. This result was the reference for the study. E10 sample was put into the tank and the engine was run to record the output. Similar steps were repeated for E20 and E30 samples, respectively. The results obtained for the E10, E20 and E30 samples were compared to the reference sample (E0).

After setting up the engine, the following measurements were taken. Using a rotating turbine flow meter, flow rate of fuel was measured, which was then converted to mass flow rate. Air flow can also be measured in the same way. After that, the force on the dynamometer was measured using a scale. The exhaust gases emitted (NOx, CO, CO₂ and O₂) were measured using a gas analyser.

Table 3. Specification of the engine.

| Model               | Subaru EX 21                                      |
|---------------------|---------------------------------------------------|
| Type                | Air-cooled, 4-cycle, slant single cylinder, OHC, |
| Bore x Stroke       | 67 x 60                                           |
| Piston displacement | 211                                               |
| Continuous Output   | 3.2(4.4)/3000                                     |
| Maximum Output      | 5.1(7.0)/4000                                     |
| Maximum Torque      | 13.9/2500                                         |
| Direction of Rotation| Counter clockwise as viewed from PTO shaft        |
3. Results and discussion

3.1. Properties test

Viscosity is the measure of flow resistance in a liquid. Viscosity is an important property for fuels as fuel is injected into combustion chambers. If viscosity is too low, the fuel flows very easily and as a result, the lubricating film between static and moving parts in the engine carburetor. On the other hand, if viscosity is too high, fuel atomization will not produce small enough fuel droplet to achieve good combustion in the engine. The values for kinematic viscosity of the samples at 30 °C are shown in figure 5. They were found to be 10.56%, 23.32% and 35.75% more viscous than the petrol sample (0.4876 mm²/s) for the samples of E10, E20 and E30 respectively. The viscosity values of the blends show a continuous and linear increase, as shown in figure 5.

![Figure 5. Variation of viscosity values.](image)

The Calorific Value is the energy contained in a sample, and it is determined by the complete combustion of a known quantity of the sample. The calorific values of the different blends along with the gasoline sample are shown in figure 6. The calorific values of the samples show a decline in calorific value with each increase in ethanol content. This decrease in calorific value in the blends is due to ethanol having a lower calorific value of 23625 J/g [18].

![Figure 6. Calorific value trend.](image)

The density of each sample at 30 °C is shown in figure 7. The results show that the density of E10 was slightly lower than that of gasoline (0.7400 kg/L), but the other blends showed a continuous and linear increase in density value. Of the different blends tested, so far all of the blends have provided satisfying results. Further experiments, such as SI engine testing of performance and emission, will determine which blend is the most promising and practical.
3.2. SI engine test

Figures 8 and 9 show the variation of Power and Torque in terms of speed when the engine is running on pure gasoline (E0). The results show that the engine runs smoothly on E0 and there was a little deflection in the results obtained. The graphs were used as reference to compare with the results of the blends.

Figures 10 and 11 show the variation of Power and Torque in terms of speed when the engine is running on E10. From the graphs, it can be seen that the values are scattered and irregular in comparison to the values obtained from E0. From the trendline curves obtained, it can be deduced that the highest Power of 2800 W was obtained at 2350 rpm while the highest Torque of 12.5 N.m occurs at 1900 rpm.

Figures 12 and 13 show the variation of Power and Torque in terms of speed when the engine was running on E20. From the graphs, similarly, the data obtained are scattered and irregular in comparison to the values obtained from E0. From the trendline curves obtained, it can be deduced that the highest Power of 2600 W was obtained at 2400 rpm while the highest Torque of 11.8 N.m occurs at 1950 rpm.
Figures 14 and 15 show the variation of Power and Torque in terms of speed when the engine was running on E30. From the graphs also, the values are more scattered and irregular to E0, but more exaggerated than the data obtained from E10 and E20. This was because the engine was not running smoothly as there were constant misfiring. Therefore, the results obtained were inconsistent. All the results of power and torque for the engine running on E0, E10, E20 and E30 have been summarized in one graph plot as shown in figure 16.
Due to the fluctuating values obtained from the experiment, it decided to compare the results obtained for the different samples at a particular speed, in this case, at 2000 rpm. In order to obtain the values to be plotted, an average of all the values obtained for each sample at 2000 rpm was calculated and the graph was plotted as shown in figure 17.

The graph obtained in figure 17 compares the Power output obtained from each sample at 2000 rpm. E0 has the highest value of Power at 2481 W, while at 2261 W, E20 shows the lowest value of Power at that particular engine speed.

4. Conclusion
The continuous studies and development of technologies used in the processing and usage of bioethanol is pushing it to the forefront of renewable fuels. Bioethanol presents many advantages which are suitable for the environment, for energy demand as well as providing a boost in agriculture and trade. As shown by the experiments conducted, the following conclusions can be drawn:

i) The performance of the engine using bioethanol blends is almost comparable to that using pure gasoline, especially at lower ethanol content blends.

ii) Increasing the ethanol content in the mixtures make the conventional SI engine more unstable, resulting in more frequent misfiring due to speed fluctuations and higher variation in the readings obtained. With an increase in the ethanol content there was 8.86% power loss at 2000 rpm for E20, and 8.18% for E30 compared to E0.

iii) With more research and experiments, Bioethanol-fuel blends can replace pure gasoline fuels easily and with many added benefits on the same or slightly modified engines.
iv) For a country like Mauritius, with no oil natural reserves and relying mainly on oil and gas imports as their source of energy, bioethanol is a welcoming source of renewable form of energy which could be produced locally, hence, driving the country on the path to being self-sufficient in energy for the future.

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