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A Comparative Study of Performance and Emission Characteristics of S.I Engine Running with Gasoline and Its Blends with Ethanol and Locally Produced Alcohol (Arekie)

By

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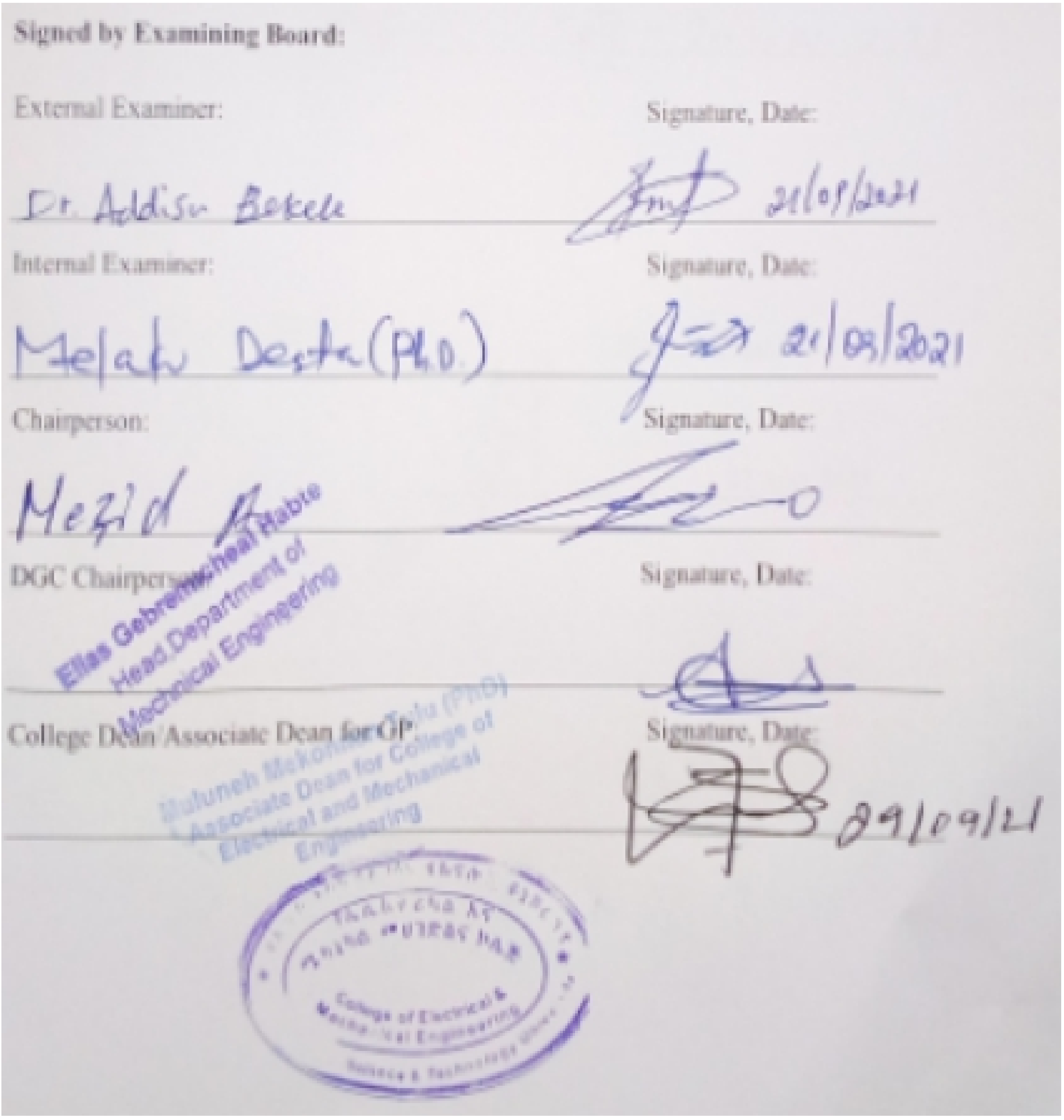
APPROVAL PAGE

This is to certify that the thesis prepared by **Mr. Mengistu Gizaw Gawo** entitled **"A Comparative Study of Performance and Emission Characteristics of S.I Engine Running with Gasoline and Its Blends with Ethanol and Locally Produced alcohol (Arekie)"** and submitted as a partial fulfillment for the award of the Degree of Master of Science in Mechanical Engineering (Automotive Engineering) complies with the regulations of the university and meets the accepted standards with respect to originality, content and quality.



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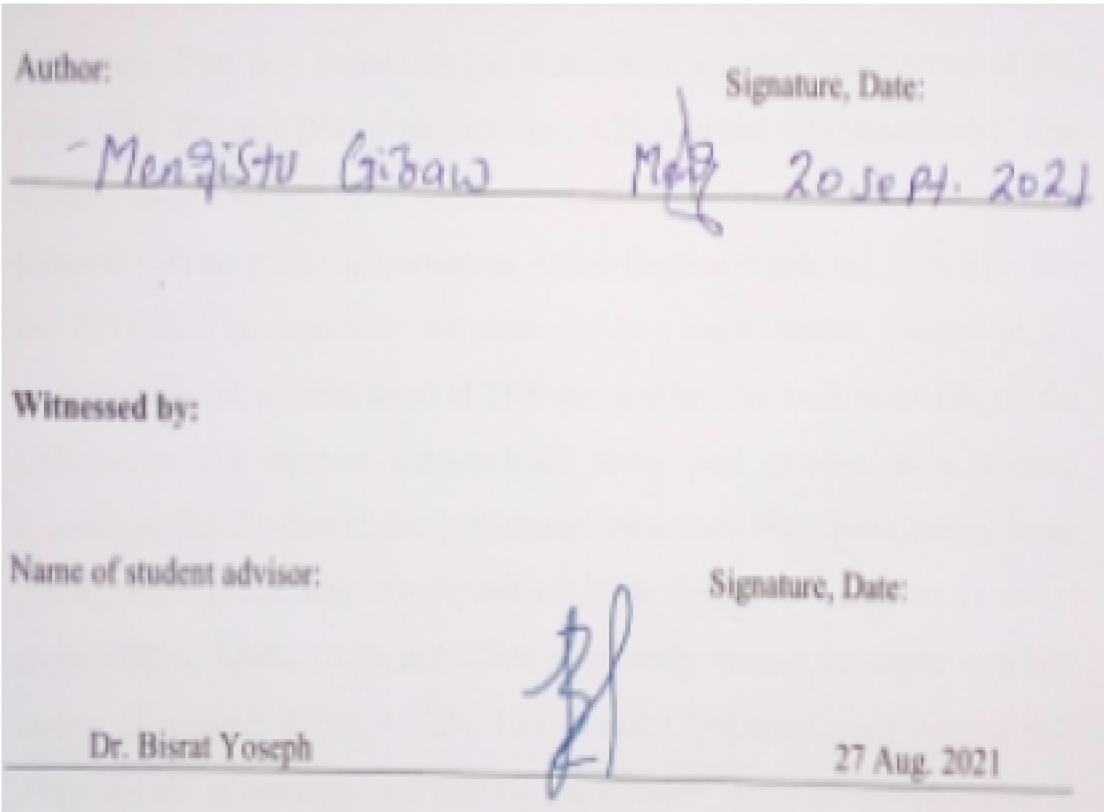
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ABSTRACT

As a result of the effects caused by petroleum fuels on global warming and climate change, the world's concern of finding environmentally friendly and less harmful alternative fuels has increased recently. Besides their harmful effects on the environment, it is not known for how long those world's number one energy sources will last. The only known and bitter fact is that they are depleting rapidly and they won't last long. Hence alcohol fuels are found to be one of the most convenient and practically proven alternatives to use in in an existing engine. In the present research work, Ethiopian locally produced alcohol (Arekie) was introduced as an alternative in the blended form with gasoline to use in spark ignition engines. The traditionally distilled Arekie was purchased from local producer and purified using fractional distillation. Then five Arekie-Gasoline blends were prepared with fraction of 5%, 10%, 15%, 20% and 25% by vol (A5, A10, A15, A20 and A25 respectively). Also absolute ethanol was purchased from local supplier and Ethanol-Gasoline blends were prepared with the similar proportions as Arekie-Gasoline blends (E5, E10, E15, E20 and E25). Then an experiment was conducted on a single cylinder, four-stroke, S.I engine running at constant speed of 2500 rpm and variable loads to investigate the performance and emission characteristics taking pure gasoline as a baseline experiment. Results showed that performance parameters like:- brake torque, brake power, brake specific fuel consumption and brake thermal efficiency are improved about 8.028%, 5.88%, 13.2% and 6.78% respectively running the engine with E20 instead of gasoline; 6.63%, 4.575%, 10.41% and 4.73% respectively running with A20. The carbon monoxide and Unburnt hydro carbon emissions are reduced up to 75.849% and 48.08% with E20; 65.65% and 46.16% with A20, while the non-toxic CO_2 emission is increased up to 7.44% and 5.354 %v/v running with E20 and A20 respectively. Among all tested fuels, E20 exhibited better performance and E25 exhibited better emission. A20 provided slightly lower performance than E20 because of its slightly increased water content but much improved compared to pure gasoline and A25 provided comparable emission to E25 and much better than pure gasoline. Generally, adding up to 20 %v/v of Ethiopian Arekie in gasoline could make a better, renewable alternative to petroleum fuels to use in spark ignition engines.

Keywords: Alcohol Fuels, Alternative Fuels, Pollutant Emissions, Spark-Ignition Engines, Engine Performance

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ABBREVIATION AND ACRONYMS

Abbreviations and Notations	Meaning
BSFC	Brake Specific Fuel Consumption
P_b	Brake Power
BTE	Brake Thermal Efficiency
Tb	Brake Torque
% (v/v)	Percentage Volume Ration of the Blends
η_{th}	Thermal Efficiency
S.I engine	Spark Ignition Engine
RON	Research Octane Number
MON	Motor Octane Number
ON	True (Average) Octane Number
HV	Heating Value
ρ	Density
A5, A10, A15, A20, A25	5%, 10%, 15%, 20%,and 25% by Volume of Arekie is Blended with Gasoline Respectively.
E5, E10, E15, E20, E25	5%, 10%, 15%, 20%, and 25% by Volume of Ethanol is Blended with Gasoline Respectively.

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CHAPTER ONE

INTRODUCTION

1.1. Background

Alcohols have been a long serving alternative fuels since the invention of the first car. Methanol, Ethanol, Propanol and Butanol are the ones the world is interested in for their compatible property to use in internal combustion engines. It was around 1896 when Henry Ford invented the world's first car and ran it with pure ethanol. Lately invented Ford model T in 1908, had the ability to move with combinations of both gasoline and Ethanol. But more scientifically the usage of alcohols as an alternative fuel for their reduced negative impact on atmosphere has increased since the middle of 1970's [1].

It is very clear fact that we are living in a world which is in an extreme danger nowadays than before and it is only going to be even worse in the future if significant pro-cautions are not taken very soon. Particularly developed countries are badly experiencing energy crisis which is caused because of their increased population number, industrialization, transportation and continuous depletion of the fossil fuels [1]. Since developing countries like Ethiopia also are transforming their economy to industry based, our world will suffer too much from the environmental change and will be affected by global warming. This is why we are noticing that even America, Australia, India and other countries are losing control of the wildfire this time because of the hot and dry environmental conditions. Therefore, it is no surprise that the world have become more concerned about reducing the use of fossil fuels as they are the source of greenhouse gases like carbon monoxide, carbon dioxide, hydro-carbons and oxides of nitrogen. Besides their toxic emissions, it is even not known for how long they will last. The only known fact is that we are going to lose them sooner than expected. Yet the world's society is left with the most sophisticated problem which has to be resolved. This is why almost each and every country is setting their future plan and alternative energy policies, so that they have been encouraging researchers towards finding renewable alternative energy sources. As a result bio-fuels are found to be a convenient alternative for the fossil fuels due to their low emission contaminants, renewability and oxygenation. Particularly ethanol is one of the most convenient alternative fuels which is able to replace fossil fuels in ICEs because of its comparative physio - chemical properties to that of regular gasoline [2]. Ethanol can run S.I engines as pure but with modifications in engine design. It is possible to use in existing design by blending it with gasoline in smaller fractions [3].

Although ethanol is produced industrially through well-known scientific procedures, many researches show that Ethanol can also be produced at home from many renewable energy sources like, farm cereals, sugarcane, and many other types of waste materials [3-5]. One of the best examples for the homemade ones is Ethiopian locally produced alcohol (Arekie). Arekie is a clear colorless traditional alcoholic beverage as that of industrially produced ethanol which is made by distillation from the fermentation products of the powders of locally available cereals like: - maize, barley, malt (Bikil), *Elusine coracann* (Dagussa), wheat, teff, etc and other ingredients like the powder of the leaf of Gesho (Ethiopian name of a specific plant) (Rhamnus prinoides).

Even if it contains too much amount of water in it because of the traditional production process, Ethiopian Arekie also is ethanol version of alcohol produced at home by local uneducated women from agricultural crops through fermentation and distillation. Ethiopian researchers have approved that locally produced alcohol (Arekie) in Ethiopia from the fermentation of beverages by distillation is said to have at least 34.09% to 46.6% (v/v) contents of alcohol (Ethanol) in it [6-8]. So, this study has shown how to purify Arekie and use it as an alternative fuel in spark ignition engines by blending it with gasoline.

1.2. Problem Statement

The energy deficiency, the continuous increment of the price of fossil fuels and fear for losing them caused significant interest in alternative energy sources to the world. Hence various researches have been performed on the usage of alcohols as alternative fuels earlier and ongoing still. As a result, Methanol and Ethanol are determined to be the common locally and industrially producible alcohols that could replace fossil fuels fully or partially [10].

Many researchers investigated the way of extracting ethanol using farm cereals, vegetables and fruits that played a crucial role in improving the S.I engine's performance and emission characteristics [11-13], but when it comes to Ethiopia, it is yet to be started. Since Ethiopia's economy is agriculture based, it has enough of those crops and farm serials to produce ethanol. Ethiopia even has a ready homemade ethanol (Arekie) which only contains some water in it and everybody knows that when he/she drinks it.

Ethiopian chemists approved that locally produced Arekie in Ethiopia is the type of Ethanol which is produced by distillation of the fermented products of agricultural crops, so that it is more likely to be alternative fuel in a blended form by only purifying it. Although it can be produced in many of urban and rural areas of Ethiopia and the production does not require any academic knowledge or special skill, it didn't serve beyond for consumption. So having the opportunity to only collect and purify it, then possibly use it as alternative fuel in S.I engines by blending with gasoline to meet Ethiopia's and the world's energy demand as well as environmental conservation policies, takes the biggest attention in this study.

1.3. Objective of the study

1.3.1. General Objective

The main objective of this research is to study the effects of blending regular gasoline with locally produced alcohol (Arekie) and industrially produced ethanol on performance and emission characteristics of S.I engines.

1.3.2. Specific Objectives

- ✓ To purify the chosen sample by undergoing fractional distillation
- ✓ To prepare blends of Arekie and blends of Ethanol with various proportions and quantify their physio-chemical properties
- ✓ To evaluate the performance, and emission characteristics of S.I engine running with gasoline as a base line experiment (E-0 or A-0)
- ✓ To evaluate the performance and emission characteristics of SI engine running with Ethanol- Gasoline blend at various ratio (E-5, E-10, E-15, E-20 and E-25)
- ✓ To evaluate the performance and emission characteristics of SI engine running with Arekie-Gasoline blend at various ratio (A-5, A-10, A-15, A-20, A-25)

- ✓ To conduct a comparative analysis of the effects caused by pure gasoline, Ethanol-Gasoline blends and Arekie-Gasoline blends on the performance and emission characteristics

1.4. Scope of the study

The first thing is to purchase the locally produced Ethiopian Arekie and measuring its physio-chemical properties. Then choosing the better sample and purify it to reduce the contained water in it is the second task. Then gasoline and industrially produced ethanol will be purchased from local gas station and Atomic Education Materials Supply PLC respectively. The comparative physio-chemical properties of those three will then be investigated. But more basically this study will focus on determining the effect of various blends of Ethiopian locally produced alcohol (Arekie) and blends of ethanol from the industries as compared to gasoline on the performance and emissions characteristics of S.I engine. To do so, experiments will be conducted at variable load and constant engine speed of 2500 rpm for five proportion of blends of Arekie (A5, A10, A15, A20 and A25), five proportions of blends of ethanol (E5, E10, E15, E20, and E25), since maximum blending ratio is not recommended; and pure gasoline as a base line experiment (A0&E0); on a water – cooled, four stroke, single-cylinder S.I engine. The experimental results of performance and emission characteristics will be analyzed and obtained through data acquisition system. Then the investigated effects through the acquired data will be interpreted, the results will be discussed and the best blending ratio will be determined.

1.5. Limitation of the study

Even though Arekie is believed to be a homemade ethanol, but its physio-chemical composition may vary according to the procedures followed in the production, ingredients used or time of stay of the fermentation because of the lack of any scientific procedures and ingredient limitations. So that the sample taken to the experiment from any place having higher or lower ethanol content may directly affect the blend’s performance. Also because of the unavailability of various devices like octane analyzer and dynamic viscosity tester and there is none to refer to, some properties of Arekie are not measured and provided here so that the discussions are only based on the obtained experimental results. In addition, this study does not consider the effect of the fuels at variable engine speed, variable compression ratio and variable environmental conditions; the experimental results will be dependent on the initial value set.

1.6. Significance of the Study

As clearly interpreted in the national energy policy of Ethiopia in 2010 the government is seeking to introduce alternative energy policy in different sectors. But particularly the government is willing to introduce the alternative energy resources development policy in transport sector to decrease the use of petroleum products by substituting new non – petroleum fuels where ever possible. So finding locally available renewable fuel sources and using them in the most efficient way is without doubt the best solution. Hence the proposed research will have a significant relevance towards fulfilling the future national and international energy, socio-economic and environmental conservation demands [13, 14].

1.7. Thesis Organization

This thesis is organized in to five main chapters. In the first chapter introduction, background, problem statement, objectives to be met, scope of the study, limitations and significance of the study are discussed. In chapter two literatures which are appropriate and most related to this study are reviewed and stated. In chapter three materials used and methods followed to conduct the study are presented. In chapter four the obtained experimental results on the performance and emission characteristics of spark-ignition engine running with gasoline, Arekie-gasoline blends and ethanol gasoline blends are interpreted and the effects caused are discussed. In the fifth and final chapter the results of the study are concluded and some specific topics are recommended for the future work.

1.8. Relevance to Government Policy

As clearly interpreted in the national energy policy of Ethiopia in 2010 the government is seeking to introduce alternative energy policy in different sectors. Particularly the government is willing to introduce the alternative energy resources development policy in transport sector to decrease the use of petroleum products by substituting new non – petroleum fuels where ever possible. Hence the proposed research will have a significant relevance towards fulfilling the policy [13, 14].

CHAPTER TWO

LITERATURE REVIEW

2.1. Introduction

This chapter intends to review the previous studies which provide assistance directly or indirectly to introduce the current study. Some journals, conference papers, books, theses and dissertations are reviewed and discussed in this chapter. The current study is about to add a new dimension in the usage of alcohol fuels as an alternative in ICEs. Particularly, it is about introducing Ethiopian locally produced alcohol (Arekie) blended with gasoline as an alternative to pure gasoline to use in spark-ignition engines. Any value adding research articles and papers related to this issue are discussed in this chapter.

2.2. Alcohol Fuels

Alcohol has been used as alternative fuel for ICEs since the invention of first car. Later in 1907 it was publicized with some reports but detailed scientific research was conducted around 1920s and 1930s. Earlier, the intention of using alcohol as a motor fuel was due to the shortage of petroleum fuels and its relatively affordability. But in the recent years It is due to its minimum toxic emissions and renewability. Ethanol is found to be an easily homemade renewable fuel which has the ability to replace fossil fuels. Even though they are good alternatives, there are also limitations of using alcohols, particularly methanol and ethanol. Although they can produce more power when used near to their stoichiometric air-fuel ratios, a larger quantity of fuel is required to generate a specified power output. They have relatively low boiling points and high vapor pressures which could cause a vapor lock if operating at higher altitudes. Vapor lock is a serious problem which occurs when the fuel changes its state from liquid to gas while it is in the fuel delivery system. They also have high latent heats which could cause difficulties in mixing the fuel with air and delivering through intake manifold. While operating in cold weather or before the engine reaches operating temperature, heating the intake manifold may be required. Unless the engine may struggle to start, or become sluggish for a while after start because of the fuel’s incomplete vaporization [20]

Recently, the usage of alcohols as an alternative fuel has become more effective due to its minimal unnecessary effects on atmosphere. Harmful effects on environment have been and are still caused by fossil fuels through their exhaust emissions such as carbon monoxide, carbon dioxide, nitrogen oxides, hydrocarbons and particulate matters. Alcohol type of fuel is said to be alternative to petroleum based fuels due to their reduced greenhouse gas emission, toxic exhaust emission and enhancement of overall energy efficiency. They are found to be convenient for ICEs due to their high octane rating, better burning velocities and excellent flammability. Alcohols with less molecular weight (methanol and Ethanol) are proven to be good alternatives to gasoline and diesel fuel in the blended form with smaller proportions [4, 5].

Studies show the addition of ethanol and methanol has improved the characteristics of base gasoline or diesel fuel which results in reduced emission and yet the performance characteristics are not affected if not improved. so based on that, this study tried to show how to produce ethanol at home from Ethiopian locally produced alcohol (Arekie) since various researches approved it contains a reasonable amount of Ethanol which in case can be even characterized as homemade Ethanol [6, 7, 8, 15]. so that it is believed to be alternative fuel for S.I engines. However, the use of pure alcohols (ethanol) as alternative fuel in the S.I engines requires some design modifications. To overcome that we blend it with gasoline in the smaller proportion to improve the characteristics of regular gasoline which leads to improve the performance and emission characteristics of S.I engine [3].

2.3. Effect of using alcohols as alternative fuel in S.I engine

The alternative fuels that have received the greatest attention to use in ICEs nowadays are bio-ethanol and bio-diesel. Bio-ethanol is produced from fermentation of any biomass that is rich in carbohydrates such as corn, sweet potatoes, cassava, millet, guinea corn, sugar cane, waste products etc. through distillation process [16].

Traditionally produced (by fermentation + distillation) alcohol fuels such as Methanol and Ethanol are effectively used as an alternative liquid transportation fuels by varying their properties, either in the pure form, in the blended form with base fuels or by the addition of certain additives. This is because their physio-chemical properties are compatible with the base gasoline fuel and have the same or higher specific energy content [4].

Numerous studies has been carried out on the possibility of using different alcohols as an alternative fuel for S.I engines by blending them with gasoline and in their pure form. They have found that bio-fuel generally improved exhaust emissions such as CO, HC, and soot allowing nearly complete combustion due to its oxygen content; notwithstanding that it has a negative effect on CO_2 and NO_x emission [17, 18].

M.K. Mohammed et al. (2021) mixed ethanol with gasoline in different proportions (10% ethanol + 90% gasoline, 20% ethanol + 80% gasoline, 30% ethanol +70% gasoline, 40% ethanol + 60% gasoline) by utilizing ultrasonic bath to ensure perfect mixing (homogeneity) which in turn will increase the fuel energy content. They used a single cylinder, four-stroke, spark ignition engine to study and analyze the effect of ethanol-gasoline blend on engine performance and exhaust gases emission. Results showed that performance characteristics such as brake power, brake specific fuel consumption and thermal efficiency are improved with the increase of ethanol concentration and caused negative effect on volumetric efficiency. They also reported that adding ethanol reduced harmful exhaust gas emissions (CO, HC, NO_x etc). It is found that adding more ethanol improved octane number of the fuel which enhances the complete burning of the fuel in the combustion chamber. Lower heating value of the blended fuels was recorded lower than that of pure gasoline but all other parameters are improved with the addition of ethanol [2].

A. Elfasakhany (2015) experimentally studied the performance and exhaust emissions characteristics of spark-ignition engine fueled with ethanol-methanol-gasoline blends. The test results obtained with the use of low concentration of ethanol-methanol blends in gasoline were compared to ethanol-gasoline blends, methanol-gasoline blends and pure gasoline test results. Combustion and emission characteristics of ethanol, methanol and gasoline and their blends were evaluated using a four stroke, single cylinder, spark-ignition engine with a bore of 65.1 mm and a stroke of 44.4 mm. The engine is a 7:1 compression ratio, air cooled, with no catalytic converter unit and a carburetor fuel system. An Electronic Ignition Control Unit (EICU) was used in the engine setup for defining the proper ignition at different loads and the engine was operated in speed range of 2600 to 3450 r/min and load of 1.3 to 1.6 KW using three different blended fuels: methanol-gasoline, ethanol-gasoline and ethanol-methanol-gasoline blends. The results showed that when the vehicle was fueled with ethanol-methanol-gasoline blends, the concentrations of CO and UHC emissions were significantly decreased as compared to the neat gasoline. Methanol-gasoline blends presented the lowest emissions of CO and UHC among all test fuels. Ethanol-gasoline blends showed a moderate emission level between the neat gasoline and ethanol-methanol-gasoline blends. i.e., ethanol-gasoline blends presented lower CO and UHC emissions than those of the neat gasoline but higher emissions than those of the ethanol-methanol-gasoline blends. In addition, the CO and UHC decreased and CO_2 increased when ethanol and/or methanol contents increased in the fuel blends. Furthermore, the effects of blended fuels on engine performance were investigated and results showed that methanol-gasoline blends presents the highest volumetric efficiency and torque; ethanol-gasoline blends provides the highest Pb, while ethanol-methanol-gasoline blends showed a moderate level of volumetric efficiency, torque and brake power between both methanol-gasoline and ethanol-gasoline blends; gasoline, on the other hand, showed the lowest volumetric efficiency, torque and brake power among all test fuels [19].

D. Y. Dhande et al. (2021) extracted ethanol from pomegranates fruits waste and used as bio-fuel. The raw juice was fermented using baker's yeast to produce ethanol. The chemical composition of the bio-ethanol produced from fermented pomegranate fruit's waste by using saccharomyces cerevisiae commonly known as baker's yeast was derived by chramatography technology. Four different blends of bio-ethanol, namely PE10, PE15, PE20, and PE25 were prepared and experimented on a kirloskar type single cylinder, four stroke, multi-fuel, VCR with open ECU spark ignition engine at various operating speeds. The results show that the addition of ethanol enhanced the fuel consumption and braking capacity. However, thermal performance was observed to be declined. PE15 blend exhibited optimum BTE at full load condition when compared with unleaded fuel. BSFC of PE15 was noticed to be lower at different operating speeds among all the blends. NO_x as well as CO_2 emissions were increased as the proportion of ethanol in pure fuel was increased. HC and CO emissions were reduced, while increasing the ratio of ethanol relative to pure gasoline, except PE10 blend. The combustion characteristics were also studied and lower value of coefficient of variation revealed stable combustion. Finally it is concluded that PE15 can be used as an alternative fuel [1].

I. Gravalos et al. (2011) Evaluated and compared the performance and emission characteristics of spark ignition engine running on ethanol and methanol blended with gasoline with that of neat gasoline. A single cylinder, carbureted, four stroke, spark ignition, non-road engine integrated with dynamo-meter and an exhaust analyzer was used for the experiment. The three proportions of blended fuels such as E10, E20 and E30 were prepared and fed to the engine. The experiment was conducted at various engine speed and the engine's, fuel consumption and load were measured while the Pb, Tb and BSFC were computed. Also after engine reached a stable working condition, emission parameters such as CO, CO_2, HC and NOx were recorded through an integrated exhaust gas analyzer. The test results show that the engine brake power is slightly increased for all engine speeds when the ethanol content of the blended fuel increased. With an increase in ethanol percentage, the density of the blend and engine volumetric efficiency increased and this caused an increase in power. The same is true for the torque. The octane number of the fuel is raised due to the addition of ethanol. Thus, anti-knock behaviour improved and allowed a more advanced timing that result in a higher combustion pressure and higher torque. The BSFC is decreased as the ethanol percentage increased, so that BTE is increased. The experimental results provided that the concentration of CO and HC emissions are decreased because of the improved combustion characteristics while CO_2 and NOx are increased (21).

H.A. Delvi et al. (2019) experimentally investigated the performance, combustion, and emission characteristics of ethanol-gasoline (Gasohol) blends with the proportions E25, E30 and E35 on a single-cylinder, four strokes, computerized spark ignition engine fitted with eddy current dynamo-meter and a precisely adjusted exhaust gas analyzer. The experimental tests were conducted under various load, engine speed and compression ratio, and the results were recorded. The results show that the performance parameters of the engine such as brake power, brake torque, brake specific fuel consumption and brake thermal efficiency were improved. Among all blended fuels E25 blend consumed less fuel at maximum speed and the BSFC was about 0.32 kg/kW-hr. The brake thermal efficiency of ethanol-gasoline blends was found to be increased compared to gasoline. Maximum BTE was found to be 27.87% for the E35 blend. For the emission parameters it is concluded that the CO emission decreases with the rise in ethyl alcohol (%) in the fuel blend. This means that there is complete combustion with the ethanol-gasoline blend. The CO concentration at 1800 rpm using E25, E30, and E35 were decreased by 11.11%, 25.92%, and 40.74% respectively compared to petrol. The reduction in CO emission was because of the reason that ethanol contains less carbon than petrol. As the engine speed increases, the HC concentration also decreases with the rise in ethyl alcohol proportion in the blend. The HC concentration at 1800 rpm using E25, E30, and E35 were decreased by 4.06%, 8.13%, and 17.88% respectively compared to gasoline. With the increment of the relative air-fuel ratio, there is a decrease in the concentration of HC emission whereas, the CO2 and NOx concentration increased with the increment of ethanol content in the blend [22].

I. Huertas et al. (2018) developed analytical and experimental work testing engines under steady conditions to address the most considerable effect when running with petroleum fuels which if the potential increase in the emissions of volatile organic compounds with high ozone formation. The carbureted and fuel-injected vehicles were tested every 10,000 km during their first 100,000 km of operation. Then the effect of using ethanol-gasoline blends on the power and the torque generated, the fuel consumption and CO,CO2,NOx and un-burned hydro-carbon emissions, including volatile organic compounds (VOCs) such as acetaldehydes, formaldehydes, benzene and 1,3-butadiene which are considered important ozone precursors were measured. The obtained results showed statistically no significant differences in this variables when vehicles operate with a blend of 20% v/v ethanol and 80% v/v gasoline (E20) instead of gasoline. Those results remained unchanged during the first 100,000 km of operation of the vehicles. It is also observed that when the vehicles operated with E20 at high engine loads, they showed a tendency to operate with a greater values of λ (ratio of the actual air-fuel ratio to the stoichiometric air-fuel ratio) when compared to their operation with gasoline. According to the Eco-Indicator-99, these results represent a minor reduction (<1.3%) on the impact to human health, and on the deterioration of the ecosystem. However, it implies a 12.9% deterioration of the natural resources. Thermal equilibrium analysis, at the tailpipe conditions (~100 ∘C), showed that ethane, formaldehyde, ethylene and ethanol are the most relevant VOCs in terms of the amount of mass emitted. The use of ethanol in the gasoline reduced 20–40% of those emissions. These reductions implied an average reduction of 17% in the ozone formation potential [23].

L. Durão et al. (2020) evaluated the addition of pyrolysis bio-gasoline (pyro-gasoline) as an additive for fossil gasoline. Pyro-gasoline was produced from used cooking oils unfit to produce bio-diesel. This study was based on a set of engine tests using binary and ternary mixtures of gasoline with 0, 2.5, and 5% pyro-gasoline and ethanol. The use of ternary blends of gasoline and two different bio-fuels was tested with the purpose of achieving optimal combustion conditions and lower emissions, taking advantage of synergistic effects due to the different properties and chemical compositions of those bio-fuels. The tests were performed on a spark-ignition engine, operated at full load (100% throttle, or WOT—wide open throttle) between 2000 and 6000 rpm, while recording engine performance and exhaust gases pollutants data. The results showed that binary mixtures with pyro-gasoline did not improve or worsen the engine's performance, but the ternary mixtures (gasoline + pyro-gasoline + ethanol) positively improved the engine's performance with torque gains between 0.8 and 3.1% compared to gasoline. All fuels presented CO and unburned hydrocarbons emissions below those produced by this type of engine operated under normal (fossil) gasoline. On the other hand, NOx emissions from oxygenated fuels had contradictory behaviour compared to gasoline. According to the gains achieved by the torque with the ternary mixtures and reductions in polluting emissions obtained by mixtures with pyro-gasoline, a future for this fuel can be foreseen as a partial replacement of fossil gasoline [24].

J. W. G. Turner et al. (2020) investigated an effect on high-blend-rate binary gasoline-alcohol mixtures and reported results for some equivalent ternary fuels from several investigation streams. It is found and presented that for high-load operation in a dedicated boosted multi-cylinder engine test facility, for operation in modified production engines, for knock performance in a single-cylinder test engine, and for exhaust particulate emissions at part load using both the prototype multi-cylinder engine and a separate single-cylinder engine. The wide variety of test engines employed has several differences, including their fuel delivery strategies. This range of engine specifications is considered beneficial with regard to the "drop-in fuel" conjecture, since the results presented here bear out the contention that when specified according to the known ternary blending rules, such fuels fundamentally perform identically to their binary equivalents in terms of engine performance, and outperform standard gasoline in terms of efficiency. Some differences in particulate emissions performance in direct-injection engines have been found at light load for the tested fuels, with a slight increase in particulate number observed with higher methanol contents than lower. Generally, it was found that these fuels do not significantly affect particulate emissions from such engines. As a result, this investigation supplies further evidence that renewable fuels can be introduced simply into the existing vehicle fleet, with the inherent backwards compatibility that this brings too [25].

M.K. Balki et al. (2014), experimentally studied the effect of alcohol (ethanol and methanol) use on the performance, emissions and combustion characteristics of a low power single-cylinder engine described the rated power output of the 2 kw and compared the results with conventional gasoline operation. The tests were performed at full-throttle valve opening and variable engine speeds. The results show that the use of alcohol fuels improved the engine's performance characteristics such as the engine's brake power, brake torque, brake specific fuel consumption (BSFC), thermal efficiency and combustion efficiency. In addition, the cylinder gas pressure and heat release rate occurred earlier. The amount of carbon dioxide (CO2) emission increased while hydrocarbon (HC), carbon monoxide (CO) and nitrogen oxides (NOx) emissions decreased because of the improvement of combustion properties [11].

Sasongko and Wijayanti (June 2017), experimentally investigated the influence of ethanol addition on the engine performance, in terms of effective power, BSFC, and exhaust emissions of a spark ignition engine. They used a 4 - stroke single cylinder, indirect injection system with engine capacity of 124.8cc, and compression ratio of 9.3:1. They conducted experiment at eight different engine speeds ranging from 1500 rpm to 5000 rpm and 10 types of gasoline-ethanol blends (E10 to E100). The obtained result showed that the effective power decreased with the increase of ethanol in the fuel blends for all variations of engine speed. Leaning effect of ethanol addition in the blend fuel caused the CO and HC emissions to decrease. On average, gasoline engine fueled by pure ethanol reduced the CO emission level by more than 60 % in volume compared to the engine with gasoline fuel. The maximum power of the engine with fuel blend was obtained at engine speed of around 2500 to 3000 rpm. For higher ethanol content on the fuel blend, the optimum shift to the lower engine speed. They concluded that engine operation with ethanol content on the fuel performed better in the lower engine speed [12].

Ahmed et al. (2017) conducted an experiment on an electric generator (spark ignition, four stroke, single cylinder, air – cooled) engine to study the influence of using ethanol – gasoline fuel blends on S.I engine. Base fuel (E0) and ethanol – gasoline blends (E5, E10 and E15) were tested at a constant speed of 3000 rpm under variable loads. The experimental results showed increment in overall efficiency and exhaust gas temperature but reduction in the total fuel consumption (FC) and specific fuel consumption (SFC). According to the test results the E15 blend delivered a comparative performance with that of base gasoline fuel/petrol and better performance among the other blends while the emission properties are improved [18].

Ramesh et al. (2013) performed experiment by blending ethanol produced from sugar cane with gasoline to evaluate the comparative performance of S.I engine at 8:1 compression ratios. According to the conducted experiment, the obtained results show maximum reduction of 2.9% with P_b for all samples at engine speed of 2000 rpm and compression ratio of 8:1. However exhaust gas emissions are improved and other parameters are presented precise. Based on the experimental, results E10 provided better performance, and exhaust emission so that it is recommended to be used as alternative in the existing spark ignition engines [26].

Yusaf et al. (2009) performed an experiment using four blends of ethanol and gasoline with (5%, 10%, 15% and 20 % ethanol addition by volume) to evaluate the performance and emission characteristics of a spark ignition engine. They draw a conclusion that the addition of 5% to 15% ethanol to gasoline increased the engine's performance parameters such as the brake torque, power output, brake thermal efficiency and the volumetric efficiency of the engine and decreased BSFC. In addition the emission parameters such as CO and HC are significantly reduced and CO2 increased with the ethanol addition because of the improved combustion properties [27].

Yinn Lin et al. (2010) investigated the influence of using ethanol-gasoline blends (E0, E3, E6 & E9) on energy efficiency and emission of a small generator at different loads and at a constant speed. The experimental results showed that ethanol-gasoline blending improved the energy efficiency and exhaust emissions and among them particularly the E6 blend provided better exhaust emissions and E9 blend provided better engine performance and particle emissions [28].

Dima Alexandru et al. (2017) compared the effects of methanol – gasoline blends on the performance, combustion and emission characteristics with gasoline. They used five different blends (M5, M10, M15, M20 and M25) to test in a single cylinder spark ignition engine. The obtained experimental results for the engine performance show a decrease of torque and power up to 10 % and emissions characteristics (CO, CO_2 and HC). They draw a conclusion that gasohol is viable option to be used in gasoline engines to replace fossil fuel partially [29].

De Simio et al. (2012) characterized the effect of different bio-ethanol/gasoline blends on engine behaviour. They tested blends until 85% of ethanol and compared combustion development of gasoline and gasoline – ethanol blends at different concentrations through the analysis of pressure cycles in combustion chamber. Additionally, emissions were collected and analyzed. So that carbon dioxide reduction with ethanol blends was achieved due in particular to better engine thermal efficiency [30].

Ko¨ten et al. (2020) performed experiment on a four-stroke, naturally aspirated, single-cylinder, spark ignition engine to study performance, and emission characteristics at full load and constant engine speed of 2400-r/min . Different levels of ethanol addition (2.5%, 5%, 10%, 15%, and 20%) into gasoline were analyzed and compared with neat gasoline fueled conditions. Obtained results showed NOx emissions increased with incremental amount of ethanol. The CO and total unburnt hydrocarbons emissions decreased while the performance parameters are not affected [31].

2.4. Physio – chemical composition of Arekie

2.4.1. Chemical composition of Arekie

As homemade alcoholic beverages are produced at home without any regular scientific procedures and standards, and according to the cereal ingredients used, the alcohol concentrations differ among different producers. Various researchers have studied the chemical compositions of arekie classifying it as "Tera (ordinary)" and "Dagim (distilled for the second time)". The alcoholic contents of Tera arekie was reported to be 34.09% (v/v). Also the average alcoholic content of Dagim-Arekie was found to be around 45% (v/v) and an average value of ethanol to be 46.6% (v/v) [6, 7,15].

Teshome et al. (2017) has quantified the Ethanol and Methanol concentrations in locally produced Arekie and reported that Arekie contains high amount of ethanol, but the results varied from producer to producer according to the specific ingredients used by producers and methods of preparation of the fermentation. Different samples of Arekie (from A1 – A5) were taken to investigation and average alcoholic content (Ethanol) of 47.56% and in the range between 0.021 and 0.187% for that of methanol were recorded [15].

Yohannes et al. (2013) investigated the physio-chemical composition of Arekie by taking different samples from Jimma, Ethiopia and observed the significant variation in PH values and alcoholic contents in the samples. According to the experimental results of this study, the PH values of different Arekie samples varied from 4.30 to 4.436 and the variation of alcoholic contents (v/v) were recorded to be 36.99% - 37.22%. Here, the difference of the samples is based on difference of producers since the samples were taken from different villages in Jimma town [7].

2.5. Some important properties considered in the fuel characterization

2.5.1. Octane Number

The Octane number often characterized as, Research Octane number and Motor Octane number, which also known as an anti-knock index is an octane booster added to gasoline to increase its octane number and reduce knocking tendency; since the gasoline produced in refineries has a low octane rating. The octane number is one of the most important properties which have the ability to define the fuel auto-ignition properties. The non-linear response of the RON with ethanol addition can conveniently be described using the Blending octane number (BON). The blending octane number is a function of the base fuel composition, the RON of the mixture and the RON of the base fuel [33].

$$\text{i.e. } \mathrm{RON_{base}.C_{base} + BON.C_{booster} = RON_{mix}} \quad (2.1)$$

Where: RON_{base} is the research octane number of base fuel

C_{base} is the volumetric composition of base fuel

BON is blending octane number of booster

B_{ooster} is the volumetric composition of the booster

RON_{mix} is the research octane number of the mixture

It is very clear that octane numbers are blended on a volumetric basis using the blending octane numbers of the components. However, True octane numbers do not blend linearly, thus it is necessary to use blending octane numbers in calculating the octane number of the blend. There are several empirical correlations that have been developed over the years to predict or estimate blending octane numbers. Blending octane numbers, when added on a volumetric average basis, will give the true octane of the blend [34].

$\text{i.e. True Octane Number of a blend (ON)} = \Sigma\, x_i * ON_i$ ---------------------- (2.2)

Where x_i is the volume fraction of component i in the blend, and ON_i is the blending octane number of component i.

Above are various prediction formulas which precisely agreed with the experimental results to predict the true octane number of blended fuels without denying that the experimental results are always better than the predicted ones. There is simple linear approximation, which clusters classes of molecules in to "lumps", which is similar to the above equations except for its representations [35].

$\text{i.e. } Q_b = Q_1 V_1 + Q_2 V_2 + \ldots + Q_i V_i$ ------------------------------------- (2.3)

Where:

Q_b = Property of blend

Q_i = Property of component *i*

V_i = Volume fraction of component *i* in blend

Therefore, we had no octane analyzer to perform experiment. So we are going to predict the improvements in the fuel auto-ignition properties using one of the above formulas. We know the volume fractions of the blends and we can have the blending octane numbers of gasoline and absolute ethanol referred to other studies. But since Ethiopian Arekie is new in this study area, its blending characteristics are not quantified yet. So we are going to predict the octane numbers of Ethanol-gasoline blends only.

Known parameters:

RON absolute ethanol = 113 [36]. Since the octane number of purchased ethanol is 99.96, its motor octane number can be obtained from the following equation.

Average ON $= \frac{(R+M)}{2} = \frac{(113+MON)}{2}$; $MON = 86.96$. This is for this study only because the MON depends on the final achieved ON. And the research and motor octane numbers of purchased gasoline (regular gasoline) is presented as follows.

i.e. **RON_g = 95 and MON_g = 80: RON_E =113 and MON_E=86.92**

Now, using one of the above formulas (say 2.2) we will obtain the octane number of Ethanol-gasoline blends as in the table 2.1 below.

Table 2-1. Octane number prediction

Blended Fuel Proportions	Octane Number (ON)
E5	88.125
E10	88.746
E15	89.369
E20	89.992
E25	90.615

According to these predictions the auto-ignition behavior of blended fuels is improved with increasing ethanol concentrations. But still the predicted results are smaller than actual results that could be obtained through experiment.

2.5.2. Heating value/Calorific value

Heating value is also a very necessary fuel property which has to be carefully investigated in the fuel characterization and engine combustion property study. It is defined as the measure of the energy content of the fossil fuels and their alternatives. The true heating value must be determined from experiment. So in this study the heating values of Ethanol, Ethanol-gasoline blends (E5-E25 and Arekie gasoline Blends (A5-A25) is obtained through experiment at room temperature of 25^{o}C using ASTM D3180 standard 1241EF Adiabatic Bomb Calorimeter.

Figure 2-1. Bomb calorimeter setup

2.5.3. Density (ρ)

Fuel density is an important fuel property which directly contributes to volumetric fuel economy and maximum power. Also reduction of fuel density can lower NOx and PM emissions while increasing HC and CO emissions [37,38]. So in this study the density of all base and blended fuels is measured using DDM 2910 Digital density tester in accordance with ASTM D4052 standard.

Figure 2-2. DDM 2910 Digital Densitometer, from Rudolf Research

2.6. Literature Gap

Ethiopian researchers have studied the physio – chemical compositions of Ethiopian locally produced alcohol/Arekie and it is found to be homemade ethanol. Other international researchers have studied, theoretically and experimentally, the possibility of using ethanol as an alternative to gasoline fuel in S.I engine by blending it with smaller proportions. Since Ethiopia, even the whole world is seriously concerned about the environmental issues, using this kind of local alternatives could have been the best solution. But Ethiopian Arekie didn't contribute more than for drinking. So this paper is about clearing the way for researchers and governmental organizations to look to ourselves and use our own alternative solutions to achieve our countries and the world's energy demand and environmental conservation policies.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Introduction

In this chapter the materials used during fuel preparation and experiment, methods used to purify the local product and to conduct the experiment, and experimental setups and procedures are all presented. Also some fuel properties studied based on measured results and calculations are presented and discussed.

In this study, it was aimed to purchase a readymade product from the legal suppliers (local gas station for gasoline and a chemical supplier for ethanol) and a chosen local producer (for Ethiopian Arekie). Then the next work was to study the physio-chemical composition s of each (Gasoline, Ethanol and Arekie) before blending. After that blending them according to the proposed proportions and fuel characterization was performed. Finally experiment was conducted on a single cylinder spark ignition engine. But there were limitations in fuel characterization because of the unavailability of many measuring instruments: like octane analyzer, dynamic viscosity tester, flash point tester etc. Since these and some unmentioned devices were not found the conclusion was drawn based on the final test results. In addition while blending, Arekie made a phase separation with gasoline because of it density resulted from high amount of water contained in it so that purifying it using fractional distillation was performed to improve its alcoholic content and blending properties.

3.2. Materials used

There are several materials and instruments used to conduct this study as presented in the figures below.

Table 3-1. Materials used for the fuel preparation

No	Material	Quantity
1	Regular Gasoline	15 litters
2	Ethanol (99.96%)	2 litters
3	Arekie sample one	2 litters
4	Arekie sample two	2 litters

Figure 3-1. Materials used for the fuel preparation

Table 3-2. Instruments used in fuel characterization

No	Instrument	Purpose	Standard	Manufacturer
1	A laboratory thermometer	To measure boiling point	-	-
2	1241EF Adiabatic Bomb Calorimeter	To measure calorific (heating value)	ASTM D3180	Parr Instrument Company, U.S.A
3	DDM 2910 Digital density tester	To measure density	ASTM D4052	Rudolf Research Analytical
4	Alcoholmeter	To determine alcoholic content	-	-

Table 3-3. Instruments used in the experiment

No	Instrument Name	Purpose
1	Fuel flow meter	Measure fuel flow rate
2	Crank angle sensor	Measure the crank angle
3	In – cylinder pressure sensor	Measure In – cylinder pressure
4	Load cell/ dynamometer	To control the load
5	Exhaust gas temperature sensor	To measure the exhaust gas temperature
6	Emission analyzer	To measure the CO, CO_2, HC & NO_x emission
7	Spark ignition engine	To perform the experiment
8	Data acquisition computer with installed specific software	To record and compute the test results

Note: these are all installed on the engine integrated to the provided data acquisition computer and provided specific software which analyzes and computes the results.

Table 3-4. Technical specifications of the test stand

Power Supply	400 V, 3~50 Hz
Dimensions	LxWxH:1480 x 850 x 1880 mm
Weight:	Approx. 245 kg
Asynchronous Motor	
Max. Output	Power: 7.5 kW
Nominal Speed:	2900 rpm
Frequency Converter	
Output Power:	7.5 kW
Power Return Unit	
Output Power:	13.0 kW
Fuel Pump: 12 V	
Qmax:	130 L/h
Measuring Ranges	
Speed Measurement:	0...9999 rpm
Torque Measurement:	0...50 Nm
Air Consumption Measurement:	0...560 l/min
Engine Intake Pressure Measurement:	0..-1 bar
Ambient Temperature Measurement:	0...100 °C
Fuel Temperature Measurement:	0...100 °C
Cooling Water Temperature Measurement:	0...100 °C
Exhaust Gas Temperature Measurement:	0...1000 °C
Fuel Measuring Tube	
Measuring Tube Inside Ø:	24 mm
Bypass Inside Ø:	9mm
1 cm measuring tube	Volume 5.1 cm^3

Table 3-5. Technical specifications of the test engine

Engine Type	Air - cooled, single cylinder, 4 - stroke petrol engine
Manufacturer	G.U.N.T
Dimensions (LxWxH)	500mm x 345mm x 410mm
Weight	Approx. 34 kg
Compression ratio	8.5:1
bore	89 mm
Stroke	63 mm
Connecting rod length	110 mm
Crank throw	31.5 mm
Maximum Power	7.5 kw
Maximum Speed	3600 rpm
Maximum Torque	24.6 Nm @ 2200 rpm
Oil Capacity	1.4 litters
Ignition	Magneto ignition
Sound level (distance 1m)	96 dB(A)

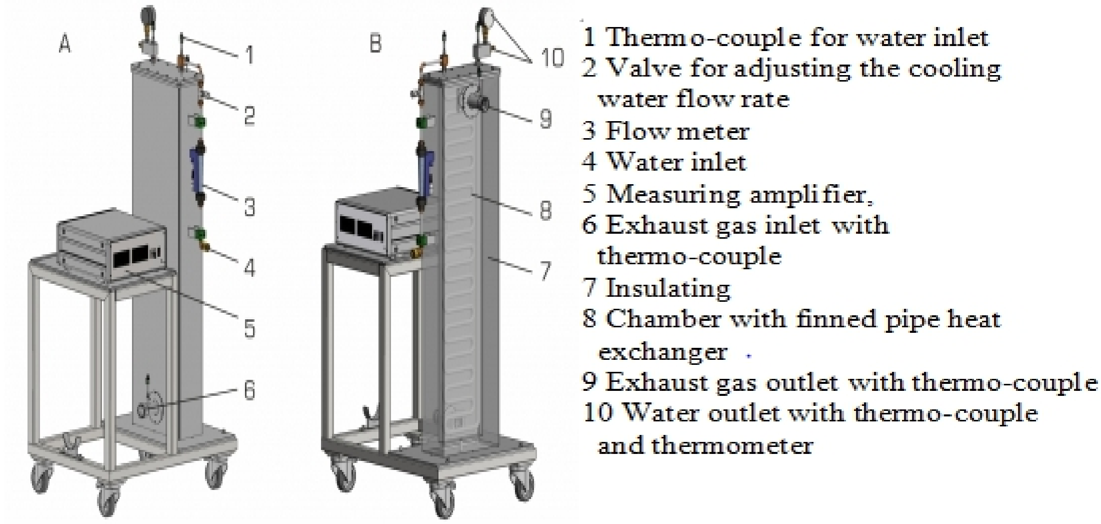


Figure 3-2. Schematic diagram of Exhaust gas Analyzer

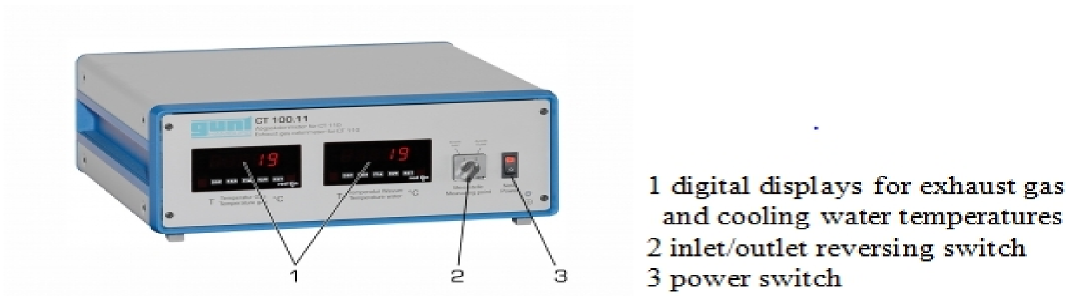


Figure 3-3. Measuring amplifier

Table 3-6. CT 100.11 Exhaust gas analyzer technical details

Model	Infralyt smart
Measuring Principle	NDIR
Dimensions (LxWxH)	570mm X 570mm X 1300mm Weight = Approx. 105 kg
Temperature measurement	Sensor: Thermo - couple type K Measuring range = 0 - 1000 ^oC
Water flow-rate measurement	Variable - area flow meter Measuring range = 30 - 300 litre/h
Display unit power supply	230 V, -50 Hz
Exhaust gas measuring range	
CO	0 to 10 %vol
CO_2	0 to 20 %vol
UHC	0 to 10000 ppm vol.
O_2	0 to 25 %vol

3.3. Methods

3.3.1. Purification of Arekie (Fractional distillation)

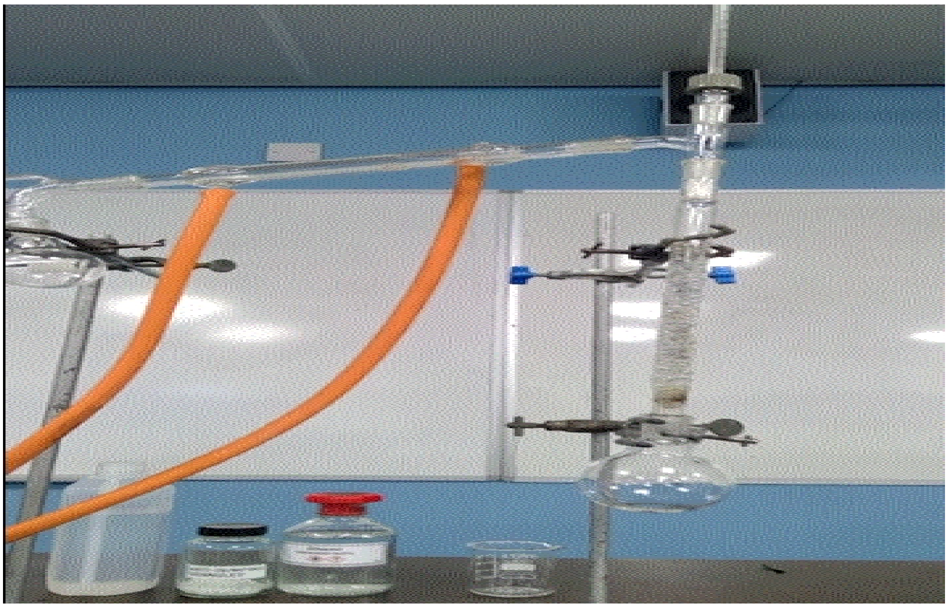


Figure 3-4. Fractional distillation

It is well known that fractional distillation is a method for separating a liquid from a homogeneous mixture of two or more liquids. But this will happen if the boiling point of the substances contained in the mixture is different. So, in this case we had two samples of Ethiopian locally produced alcohol (Arekie) purchased from **“Semen Korea Arekie bet”** meaning North Korean Arekie house in Debre-Birhan; whose alcoholic content was measured to be 48 %v/v and 51 %v/v for the sample one and two respectively. Which means around half of the sample contained in it was water without denying the fact that there is also small concentration of other components like methanol. Therefore, this led as to undergo fractional distillation. Since ethanol boils at 78°C and water boils at 100°C, **ethanol** can be separated from a mixture of ethanol and water by fractional distillation. When we heat the mixture, ethanol evaporates before water. After the process we have found an alcoholic content of around 95 %v/v. notice that the maximum alcoholic content we can have through fraction distillation is 95%v/v.

Table 3-7. Comparison of properties before and after fractional distillation

Property	Before Fractional Distillation		After Fractional distillation
	Sample 1	Sample 2	
Alcoholic Content (%v/v)	48	51	95
Density, ρ (g/m^3)	896.8	890.35	798.975

The fractionally distilled Arekie looks clearer than the purchased one and its alcoholic content is much improved so that the density is reduced as enough as possible not to form a phase separation during blending.

(a) Before fractional distillation (b). After fractional distillation

Figure 3-5. Arekie before and after fractional distillation

3.3.2. Fuel preparation by blending

As mentioned above, Arekie was purchased from local producer and its alcoholic content was measured to be nearly 50% by volume. However it was blended with smaller proportions (A5 and A10) directly as purchased and phase separation was observed as Arekie sunk down to the bottom of the container as shown in the figure below. It somehow was taken to the experiment on the engine running at constant speed of 2500 rpm and at full load (throttle valve at wide open position) and its efficiency was recorded around 12% for A5 and less than 10% for A10. The reduction of performance happened because the gasoline absorbed some water during blending.

Figure 3-6. Phase separation of the blends prepared before fractional distillation

So to overcome this blending properties (phase separation), we needed to purify the Arekie using fractional distillation to evaporate and collect the ethanol contained in it at the temperature of between 78°C to 82°C. Therefore, the collected ethanol from Arekie (purified Arekie) was obtained having an alcoholic content of 95 %v/v. (Note that the maximum alcoholic level to be achieved is 95.5 %v/v). After purification its boiling point was measured to be 80.5^{o}C. Compared to the pure ethanol, the boiling point is raised by 2.5^{o}C; but was not bad during blending. The phase separation was completely eliminated and the blended solution was actually similar to that of pure ethanol blends. After realizing that the blending property of Arekie was much improved, all the proposed blending proportions were prepared starting from 5%v/v up to 25%v/v with a fraction of 5% (i.e. A5, A10, A15, A20 and A25) for purified Arekie-gasoline blends and similarly (E5, E10, E15, E20 and E25) for that of absolute Ethanol-gasoline blends.

Figure 3-7. Blended fuels of Arekie-Gasoline and Ethanol-Gasoline

3.3.3. Fuel Characterization

Five proportions of fuels were prepared by blending Ethiopian locally produced alcohol (Arekie) and purchased absolute Ethanol with pure gasoline at 5%, 10%, 15%, 20% and 25% in a volume basis for each at a room temperature of 20^{o}C. Then heating values of Ethiopian Arekie, pure Ethanol and their blends were calculated using a 1241EF adiabatic bomb calorimeter. Also densities of both and their blends were measured using an ASTM standard D4052 digital density meter. Because of unavailability of other devices, other parameters are referred to other researchers. But particularly, octane number is calculated using the concept of linear blending.

CHAPTER FOUR

EXPERIMENTAL PROCEDURES AND DESIGN

4.1. Experimental Setup

A water cooled, four stroke, single cylinder spark ignition engine running at constant speed of 2500 rpm under variable loading conditions was used to study the effects on the performance and emission characteristics fueled with Gasoline, Arekie-Gasoline blends and Ethanol-Gasoline blends. The engine was started and allowed to run for at least 10 minutes to warm up before starting the test. After realizing the engine has warmed up and constant speed of 2500 rpm was achieved, gasoline fuel was fed and the records of performance parameters such as brake torque (Tb), brake power (Pb), brake specific fuel consumption (BSFC) and thermal efficiency (η_{th}) were taken by the data acquisition system and the CO, CO_2 and HC emissions results were captured from the emission analyzer display screen at no load, 25%load, 50%load, 75%load and full (100%) load conditions. The remaining fuel was drawn out through return unit and the engine was allowed to run for 2 minutes without fuel to make sure of the complete consumption of the previous fuel before jumping to the next experiment. Similar procedures were taken for all of Arekie-Gasoline blends (A5, A10, A15, A20 and A25) and Ethanol-Gasoline blends (E5, E10, E15, E20 and E25). The test engine was connected to asynchronous motor that operates as a dynamometer which enables us to control the load. The test stand was equipped with a measuring tube for fuel measurements and with a measuring orifice for air consumption measurements. Apart from measurements on the consumption of fuel and combustion air, the Test Stand for Small Internal Combustion Engines is used in these experiments to measure the torque and speed on the engines employed. And the relevant measured values are indicated on clear displays as shown in the Figure 0-8 below.

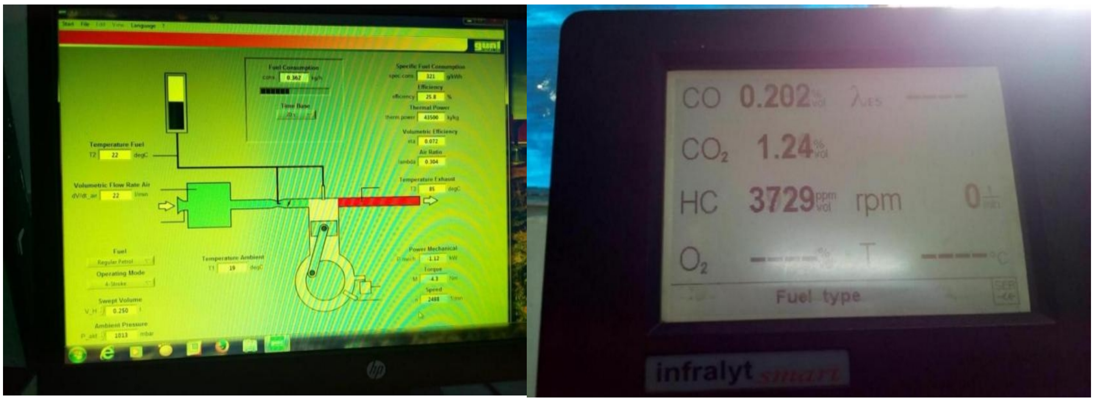


Figure 4-1. Data acquisition and display after computation

Electronic sensors were provided to record the ambient temperature, fuel temperature and exhaust temperature. Also an Electronic Indicating System with a Spark Plug Pressure Transducer (CT 100.13 and CT 100.14) and an Exhaust Gas Calorimeter (CT 100.11) that displays the exhaust emission were connected to it. The data acquisition system which takes the records of the electronic sensors and display devices and performs computation of performance characteristics through a specific software provided by the manufacturer was integrated to the test stand.

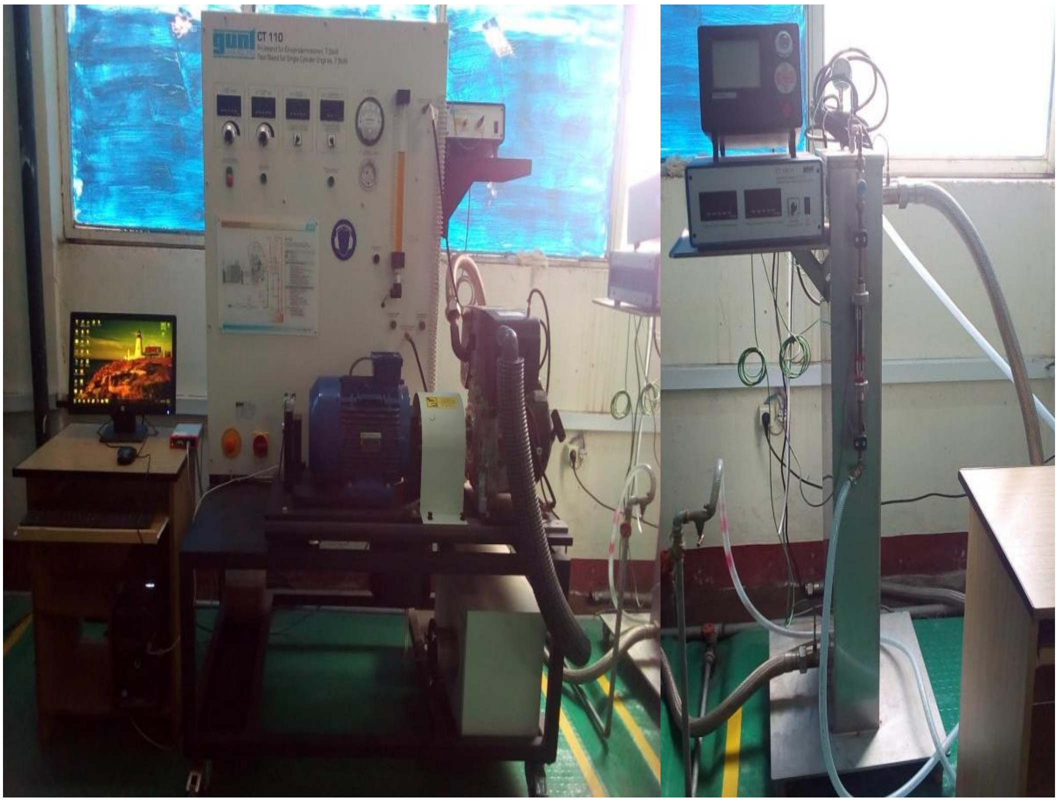


Figure 4-2. Actual setup of the test stand with emission analyzer

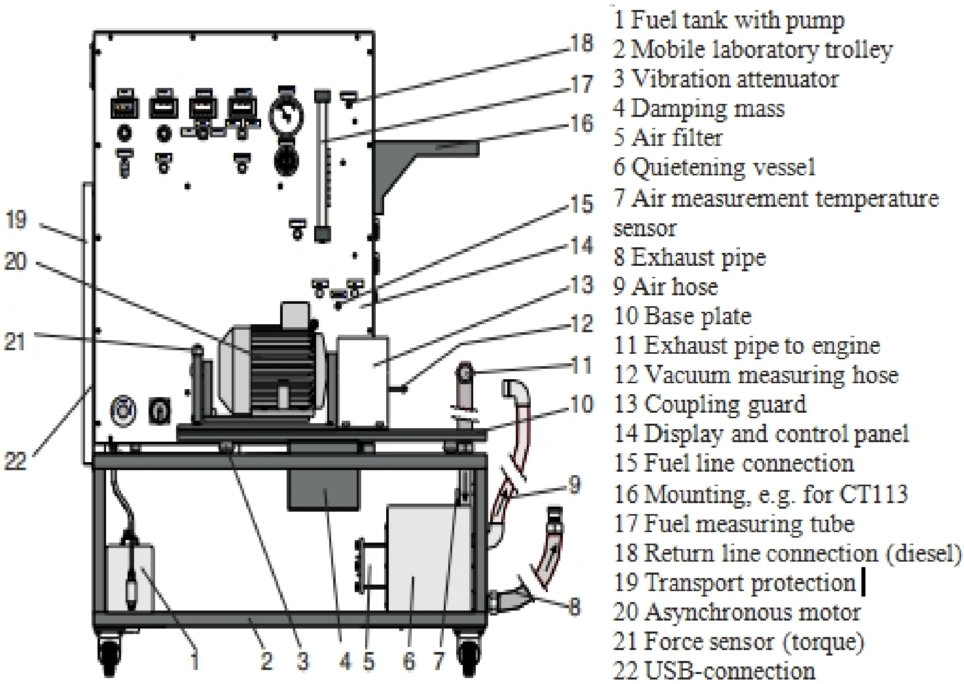
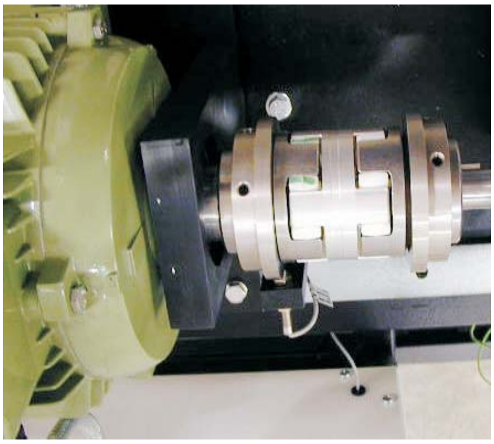


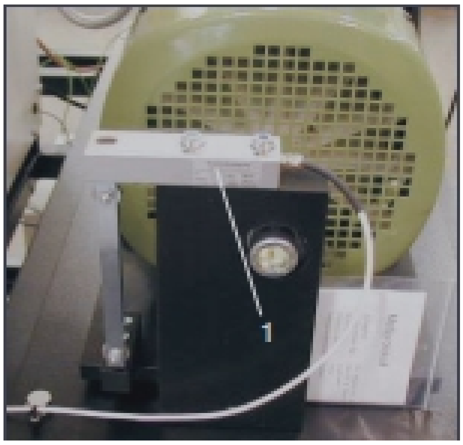
Figure 4-3. Schematic diagram of the test stand

i. Speed Measurement

The speed is measured using an inductive proximity switch that is fitted to the coupling on the braking device (Fig. a). The speed is indicated on a digital display in revolutions per minute.



(a) Speed Measurement



(b) Torque Measurement

Figure 4-4. Speed and Torque Measurements

ii. Torque measurement

The braking device is mounted in floating bearings and thus facilitates the direct measurement of the torque (fig.b). An electronic force sensor measures the supporting force proportional to the torque. An electronic device calculates the engine torque using the lever arm at the point at which the sensor is attached. The values are displayed on a digital scale in Nm.

4.2. Experimental Procedures

The first test was performed using pure gasoline (E0, A0) as a baseline experiment aiming to compare other results with it. Also Ethiopian Arekie was blended with gasoline at smaller proportions (A5 and A10) directly as purchased from local producer before fractional distillation. But these results did not goes well during experiment since the blend from the beginning did not seem well as it sunk down forming phase separation with gasoline because of the amount of water contained in it. Having taken to the experiment with this visible problem, it practically affected the performance and emission characteristics of the engine. The test results of A5 at constant speed of 2500rpm, 8.1 compression ratio and at full load condition showed that the maximum efficiency achieved is 16.0378% , brake /Mechanical power is 0.9248 and torque is 3.53 which is very poor performance compared to gasoline at similar conditions. A10 even reduced this efficiency to 12% and other performance parameters are reduced further as expected. Realizing that further addition of Arekie will much reduce the performance of the engine stopped the test. Otherwise it might have caused a significant damage to the engine. So went back and purified the Arekie through fractional distillation. Now the fractionally distilled Arekie was blended to base gasoline and the blends made homogeneous mixture as that of absolute ethanol. Then the experiment is well performed once again With both blends of Arekie and blends of absolute ethanol and good results were obtained.

CHAPTER FIVE

RESULTS AND DISCUSSIONS

In this chapter the investigated comparative effects of Arekie-Gasoline blends, Ethanol-Gasoline blends and pure gasoline on the performance and emission characteristics running the spark- ignition engine with each of them are presented.

5.1. Fuel Properties

The following table shows the measured and calculated fuel properties with the equipment standards.

Table 5-1. Measured and calculated Fuel Properties

No	Fuel Grades	Fuel Properties		
		Heating value (KJ/kg)	Density (g/m^3)	Octane Number
1	Gasoline	44200	742	87.5
2	Ethanol	29500	785	99.96
3	E5	43191	744.15	88.125
4	E10	42185	746.3	88.746
5	E15	41235	748.75	89.369
6	E20	40430	750.6	89.992
7	E25	39578	752.75	90.615
8	Arekie	32100	798.975	-
9	A5	43595	744.84	-
10	A10	42990	748	-
11	A15	42385	751	-
12	A20	41780	753.4	-
13	A25	41175	756.24	-

5.2. Performance

5.2.1. Brake Torque

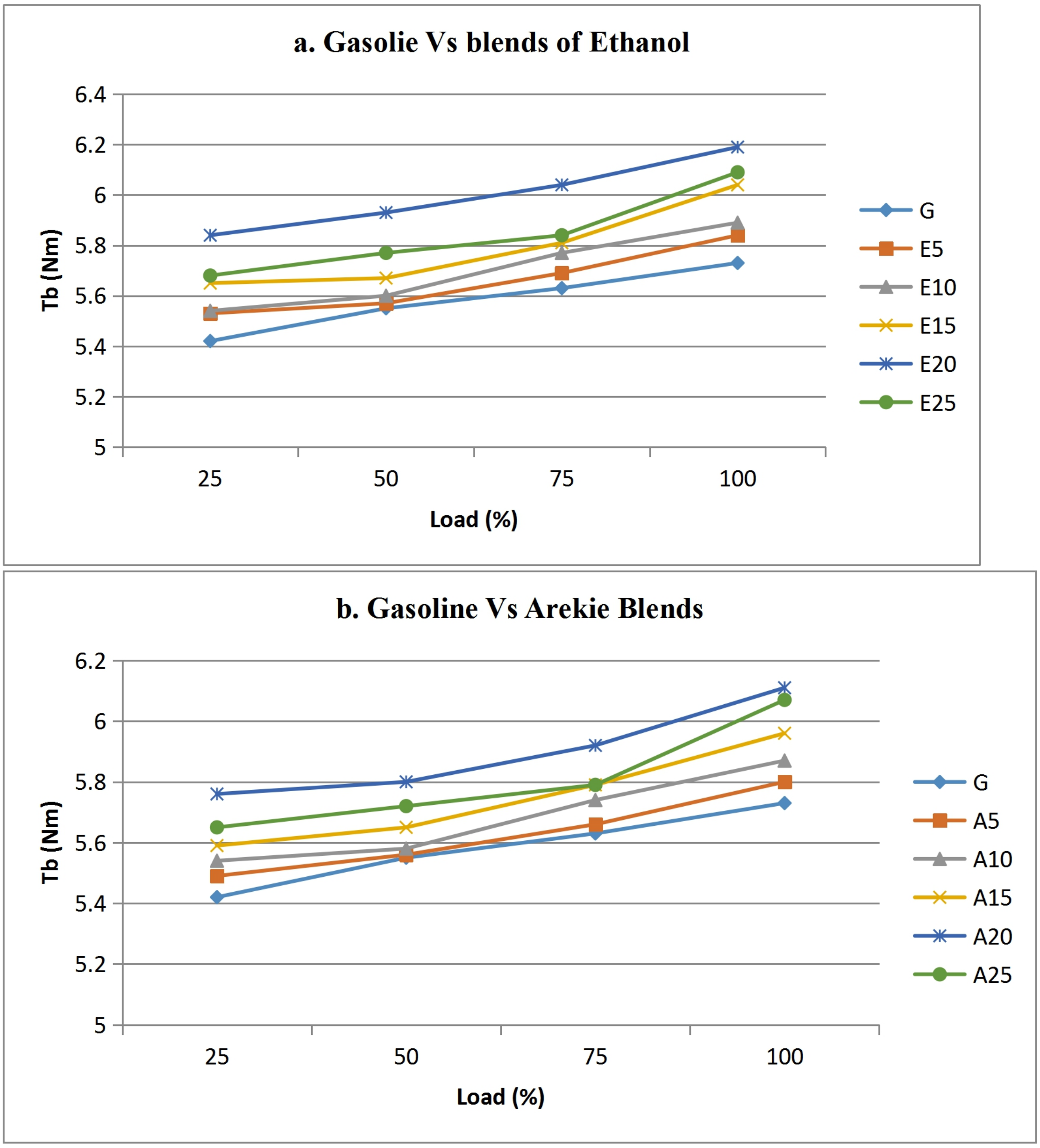
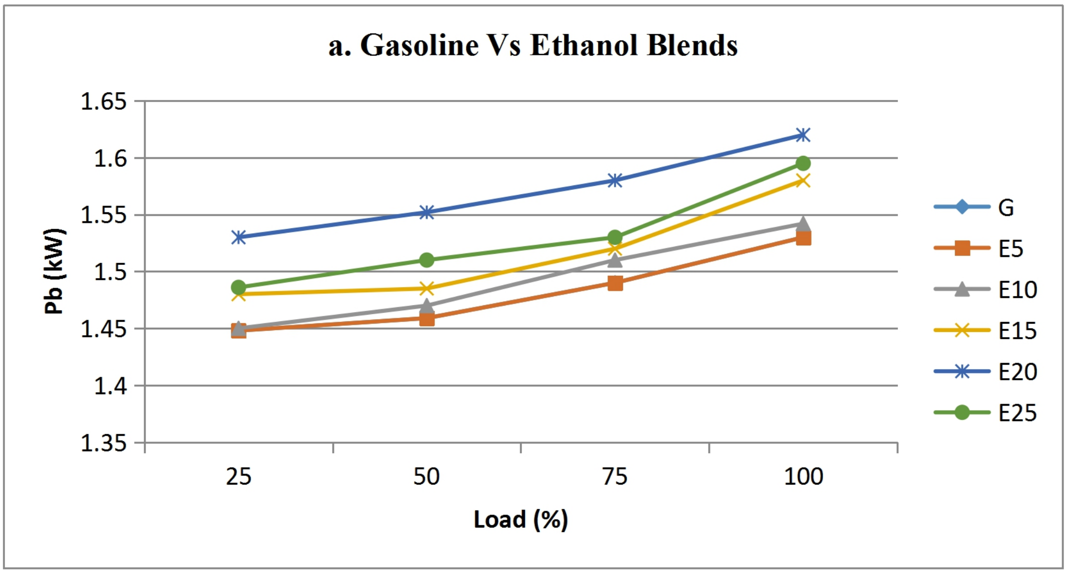


Figure 5-1. Generated Brake Torque @ constant Speed and Variable load

Figure 5-1. According to the obtained experimental results, the generated Brake torque of the test engine was significantly improved with the addition of both Ethiopian Arekie and absolute ethanol at all loading conditions. As compared to gasoline, E5, E10, E15, E20 and E25 has shown 0.11, 0.12, 0.23, 0.42 and 0.26 Nm respectively, improvements at 25% loading conditions. This is 2.03%, 2.214%, 4.24%, 7.75% and 4.8%. Similarly, Ethiopian Arekie after Fractional distillation has shown a slight increment as well. A5, A10, A15, A20 and A25 provided 0.07, 0.12,

0.17,0. 34 and 0.23 Nm respectively improvements at 25% loading condition. Which is 1.29%, 2.214%, 3.136%, 6.273% and 4.24% increment compared to gasoline. But Ethiopian Arekie has shown a slightly reduced or equal result compared to absolute ethanol throughout the experiment. At 50% loading conditions, E5, E10, E15, E20, E25 improved the brake torque with 0.02, 0.05, 0.12, 0.38 and 0.22 Nm. this is 0.36%, 0.9%, 2.162%, 6.847%, and 3.96% and A5, A10, A15, A20 and A25 improved with 0.01, 0.03, 0.1, 0.3 and 0.17 Nm. That is 0.2%, 0.54%, 1.8%, 5.4% and 3.063%. This time gasoline itself has improved the torque with 0.13 Nm (2.33%) from the previous 5.42 Nm at 25% load because of the increased loading. At 75% load, E5, E10, E15, E20 and E25 caused the torque with 0.06, 0.14, 0.18, 0.41 and 0.21Nm (1.0657%, 2.4867%, 3.197%, 7.28% and 3.73%, respectively) increment. Arekie blends too has given 0.03, 0.11, 0.16, 0.29 and 0.16 Nm (0.533%, 1.954%, 2.842%, 5.15% and 2.842% respectively) improvement in brake torque. The gasoline improved brake torque with 0.08 Nm (1.44%) and 0.21 Nm (3.87%) compared to 5.55 Nm at 50% and 5.42 Nm at 25% load. The torque does not stop improving with the increment in load as E5, E10, E15, E20 and E25 gave 0.11, 0.16, 0.31, 0.46 and 0.36 Nm (1.92%, 2.792%, 5.41%, 8.028% and 6.28% respectively) and A5, A10, A15, A20 and A25 gave 0.07, 0.14, 0.23, 0.38 and 0.34 (1.22%, 2.443%, 4.014%, 6.63% and 5.93% respectively) improvements to the brake torque of the test engine at full (100%) load. The pure gasoline improved the torque too by 0.1, 0.18, 0.31 (1.845%, 3.321%, 5.72% respectively) at full load compared to previous 75, 50 and 25% partial loading conditions. ***Refer table-5-2 in appendix 2 for complete brake torque result.***

5.2.2. Brake Power



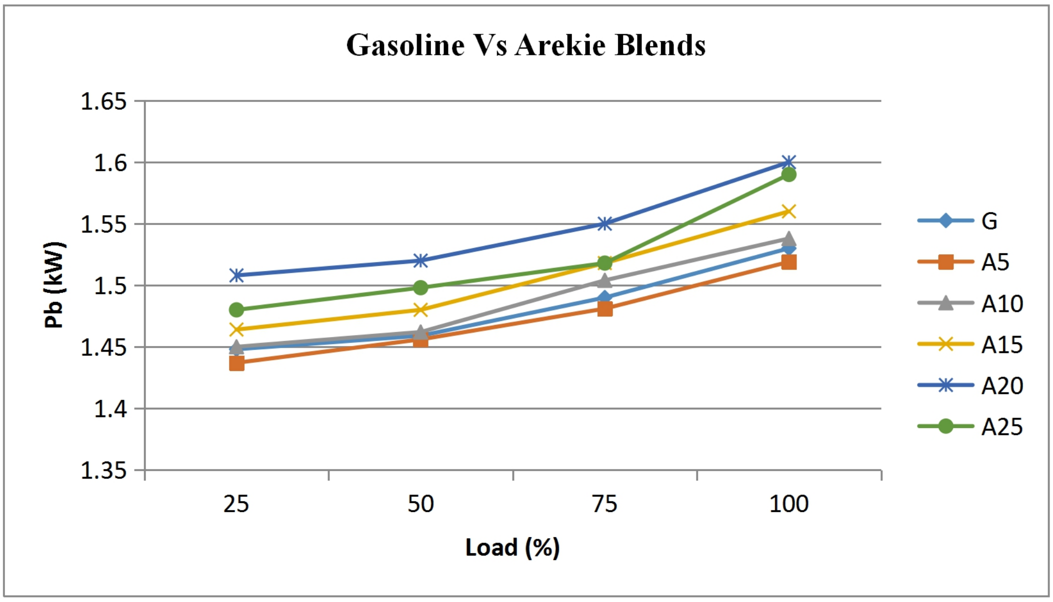
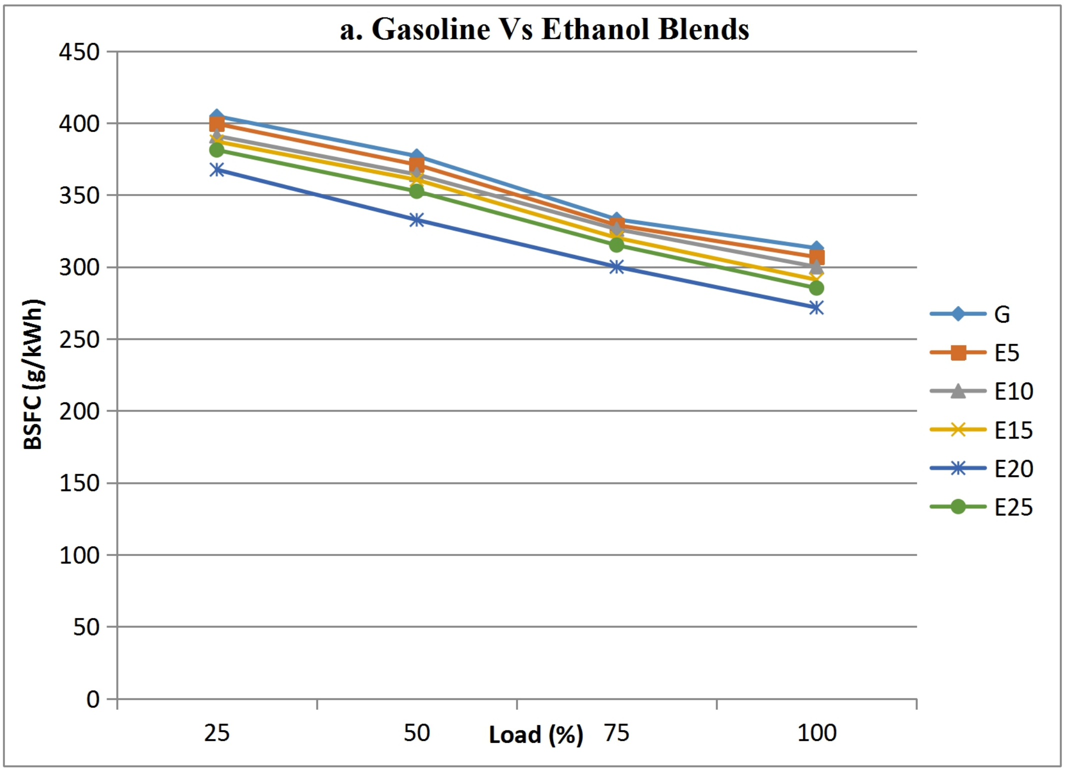


Figure 5-2. Generated Brake Power @ Constant Speed and Variable Load

Figure 5-2. As for brake torque, the improvements are noticed for brake power of the test engine at all loading conditions. Additionally, the increment in concentration of ethanol and Arekie resulted in significant improvement of brake power too. According to the recorded results from the experiment, the engine was able to generate 1.448 KW brake power running with pure gasoline at constant speed of 2500 rpm and 25% load. If this is compared to the 1.448, 1.45, 1.48, 1.53 and 1.486 KW power that the engine generated running with E5, E10, E15, E20 and E25 respectively at the same running conditions, the improvement in the brake power will be 0%, 0.138%, 2.21%, 5.663% and 2.624% respectively. For A5 there was a reduction of 0.76% reduction in brake power but A10, A15, A20 and A25 still improved the result by 0.138%, 1.105%, 4.1436% and 2.21%. At 50% load the brake power of the engine running with gasoline was recorded to be 1.459 KW. For the similar running conditions, the blends of ethanol E5, E10, E15, E20 and E25 improved the brake power with 0%, 0.754%, 1.782%, 6.374%, 3.495% respectively. but, A5 reduced it by 0.2056% & A10, A15, A20 and A25 still improved it by 0.2056%, 1.439%, 4.18%, and 2.673%. At 75% load, brake power of the engine running with gasoline was 1.49 KW and all proportions of blends of Ethanol has provided improvement in brake power except for E5 which has similar recording with that of gasoline at all loads. And all proportions of Arekie blends has shown improvement at all loads Except for A5 which caused a negligible reduction in brake power of the test Engine. All fuels performed well and improved brake power as the load is increased and blending also significantly improved it too. ***Refer table 5-3 in appendix 2 for complete brake power result.***

5.2.3. Brake Specific Fuel Consumption



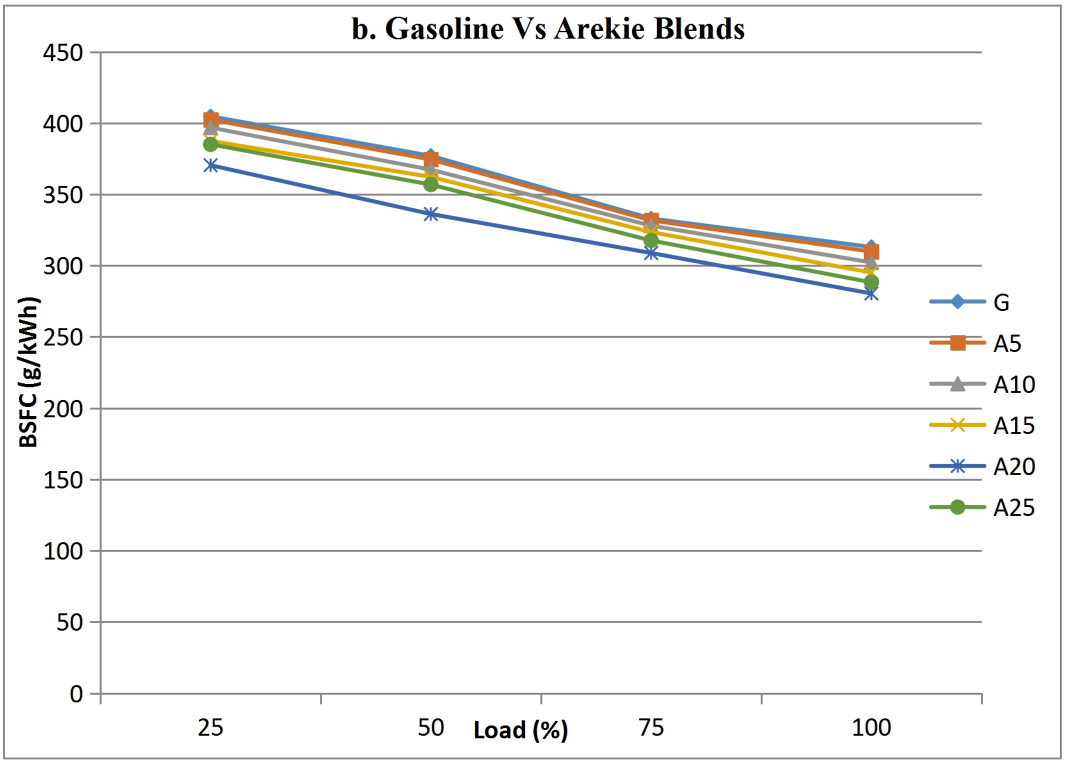


Figure 5-3. Brake Specific Fuel Consumption @ Constant Speed and Variable Load

Figure 5-3. Brake specific fuel consumption (BSFC) is also one of the most important performance parameters that were investigated in this study. Due to the test results from the experiment conducted at constant engine speed of 2500 rpm and at variable loads, the BSFC of the test engine was reduced with addition of both Arekie and absolute ethanol for all loading conditions. At 25% load, the BSFC of the test engine running with neat gasoline was recorded to be 404.7 g/kWh. It was reduced further to 377, 333 and 313 g/kWh at 50%, 75% and 100% (full) loads.

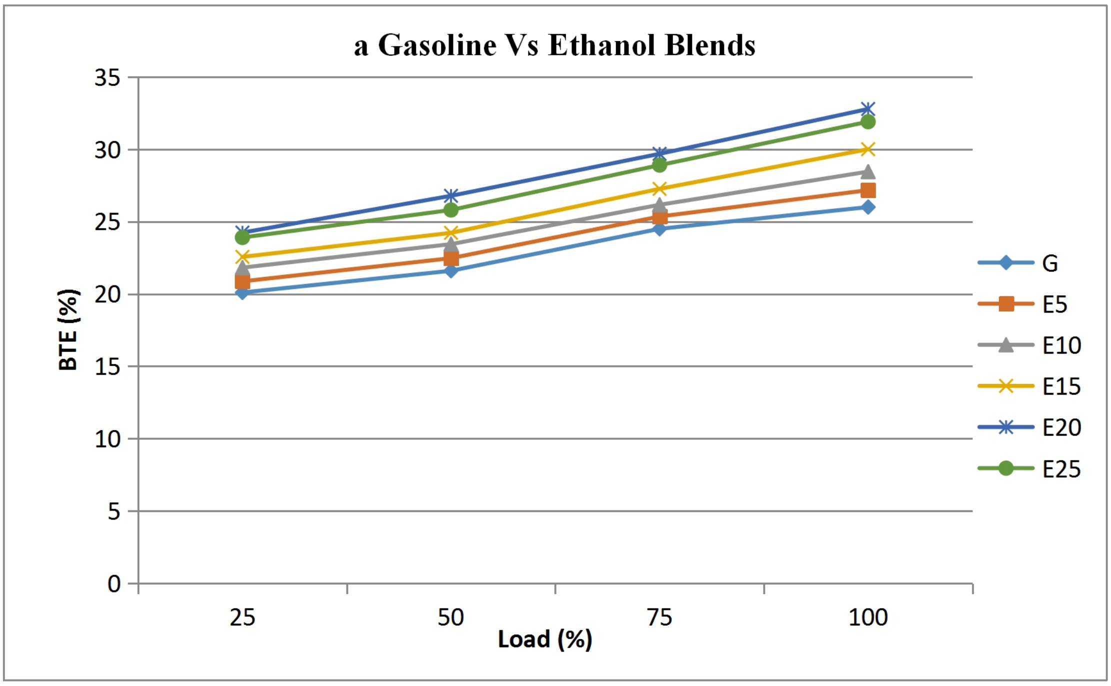
Those results were compared to blends of Arekie and blends of ethanol at specified loading conditions. Hence blends of Ethanol (E5, E10, E15, E20, E25) reduced it to 399.4, 391, 387.1, 367.54 and 381.2 g/kWh at 25% loading condition, which is 1.31%, 3.385%, 4.349%, 9.182%, and 5.8% reduction compared to 404.7 g/kWh at 25% load. Arekie blends, A5, A10, A15, A20 and A25, too reduced it by 0.58%, 1.947%, 4.275%, 8.475% and 4.858%.

At 50% load the BSFC of E5, E10, E15, E20 and E25 was recorded to be 371, 364.2, 360.5, 332.65 and 352.5 g/kWh respectively which was 1.59%, 3.395%, 4.376%, 11.76% and 6.498% reduction compared to gasoline's 377 g/kWh. And A5, A10, A15, A20 and A25 was to be 374.4, 367.261, 362.2, 336.17 and 356.8 g/kWh which was 0.689%, 2.58%, 3.925%, 10.83% and 5.358% reduction compared to that of gasoline's.

At 75% load BSFC of the engine running with pure gasoline was 333 and that of E5, E10, E15, E20, E25 were 329, 326.2, 320.2, 300.02, 315.12 g/kWh respectively. And this earns us 1.2%, 2.042%, 3.84%, 9.9%, 5.37% reduction compared to gasoline. Similar effects were noticed running with blends of Arekie (A5, A10, A15, A20 and A25) which gave 0.55%, 1.5%, 2.853%, 7.26%, and 4.63% reduction.

At full load, E5, E10, E15, E20, E25, showed 1.98%, 4.15%, 7.028%, 13.2% , 8.86% reduction an A5, A10, A15, A20, A25 showed 1.016%, 3.447%, 5.72%, 10.409% and 7.9% reduction compared to the engine's BSFC (313g/kWh) running with gasoline. For all fuels the BSFC is reduced more than 22% between 25% to 100% loading conditions. ***Refer table 5-4 in appendix 2 for complete brake specific fuel consumption result.***

5.2.4. Brake Thermal Efficiency



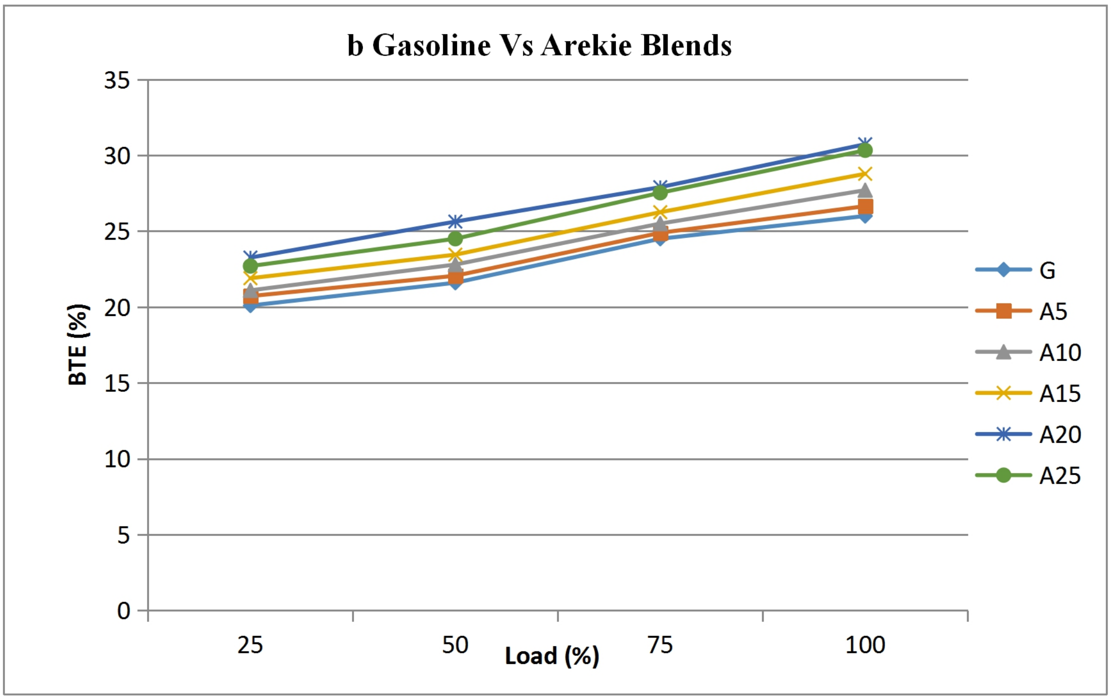


Figure 5-4 Brake thermal Efficiency @ Constant Speed and Variable Load

Figure 5-4. The thermal efficiency of the test engine was improved with the increment of the concentration of Ethanol/Arekie in the blend for all loading conditions. The test results also show that, for the specific fuel blend, the thermal efficiency of the engine was affected proportionally by the load (i.e. as load increases, brake thermal efficiency increases). As we see at figure 4-4 both blending and increased loading caused a positive impact on brake thermal efficiency.

At 25% load, the thermal efficiency of gasoline was 20.12%. At similar operating conditions, E5, E10, E15, E20 and E25 has improved the efficiency of the test engine by about 0.75%, 1.7%, 2.44%, 4.12% and 3.8% respectively and A5, A10, A15, A20 and A25 has improved it by about 0.6%, 0.98%, 1.78%, 3.14% and 2.58%. Changing our load from 25% to 50% caused the efficiency of the engine running with each fuel to improve. Running with gasoline the efficiency recorded was 21.61% which is greater than the previous efficiency by about 1.49%. equal or greater improvements was witnessed for all fuels. In addition to load effects, blending too has caused a positive impact to the efficiency. E5, E10, E15, E20 and E25 caused 0.86%, 1.83%, 2.61%, 5.17% and 4.19% improvements respectively and A5, A10, A15, A20 and A25 caused 0.45%, 1.19%, 1.84%, 4.02% and 2.89% improvements respectively compared to gasoline's 21.61% brake thermal efficiency.

At 75% E5, E10, E15, E20 and E25 has shown 0.87%, 1.68%, 2.78%, 5.2% and 4.42% respectively improvements and A5, A10, A15, A20 and A25 has shown 0.41%, 1.02%, 1.77%, 3.42% and 3.05% respectively improvements compared to that of pure gasoline which is equal to 24.48% at specified operating conditions. Because of raised load to 75%, the brake thermal efficiency of the engine running with gasoline has improved up to 4.36% and 1.49% compared to the efficiency at 25% and 50% loads respectively. The efficiency running with each proportions of the blends of both Arekie and Ethanol were similarly affected because of raised load from 25% to 50% to 75%.

Running the engine at full load improved the BTE even further. All blends of ethanol (E5, E10, E15, E20 and E25) and all blends of Arekie (A5, A10, A15, A20 and A25) improved the efficiency of the engine by 1.17%, 2.45%, 4%, 6.78%, 5.9% and 0.65%,1.7%, 2.78%, 4.73%, 4.33% respectively compared to gasoline's 26% efficiency at full load. Changing the load from 25% to full load (100%), each fuel has registered at least 5.88% improvement gasoline up to the maximum of 8.54% improvement of E20. But adding either Arekie or ethanol more than 20 %v/v in gasoline affected the air-fuel ratio or the brake thermal efficiency started to fall back. ***Refer table 5-5 in appendix 2 for complete brake thermal efficiency result.***

5.3. Emissions

5.3.1. Carbon Monoxide (CO)

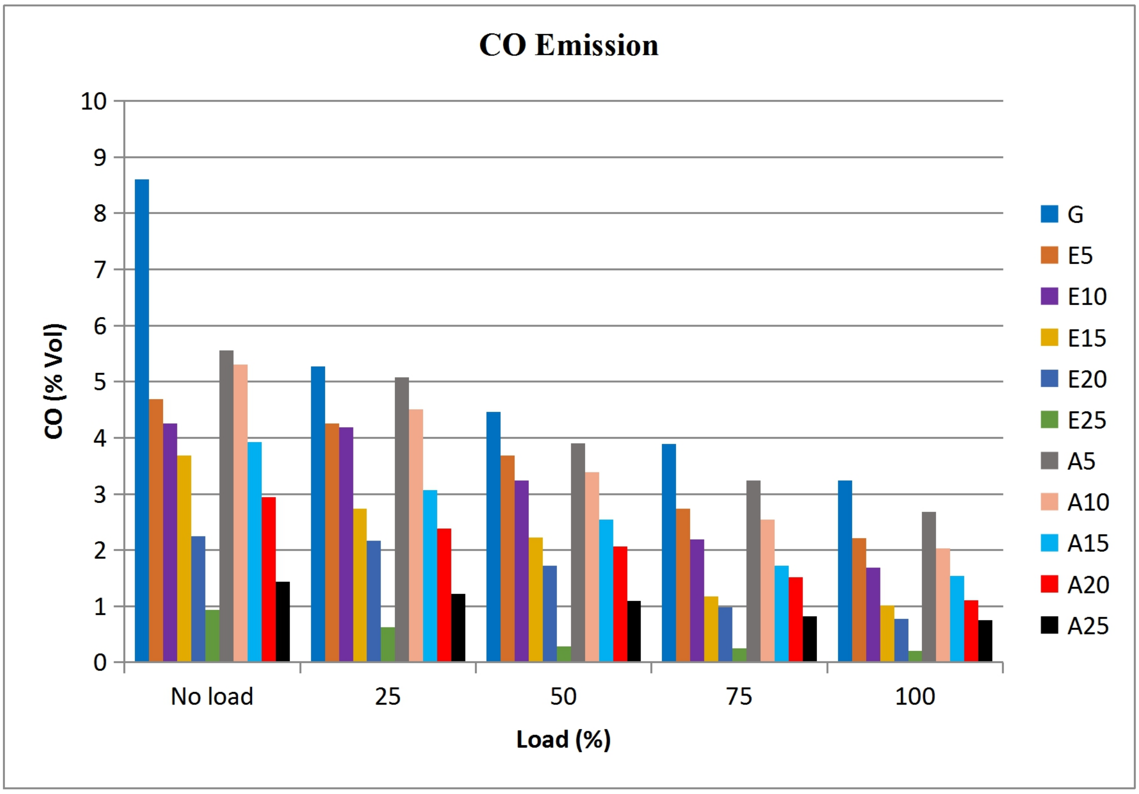


Figure 5-5. CO Emission @ constant Speed and Variable Load

Figure 5-5. CO emission is resulted in IC engines because of incomplete combustion and slow burning of air-fuel mixture by the time of combustion in a combustion chamber. According to the conducted experiment in this study, the CO emissions reduced as the load increased, which was due to the increase in combustion temperature that resulted in a complete combustion at higher loads. In addition, it was found that the CO emission of the test engine was reduced as the blending ratio of both absolute ethanol and Ethiopian Arekie increased in the fuel. This was because of the increased oxygen content and lower carbon to hydrogen ratio of bio-fuels compared to pure gasoline. The addition of either ethanol or Arekie in gasoline can increase the cetane number of the blended fuel, which helps to boost the combustion behavior of the fuel and prevents the formation of rich fuel zone. Hence reduces the CO emission. ***Refer table 5-6 in appendix 3 for full CO emission results.***

5.3.2. Carbon Dioxide (CO_2)

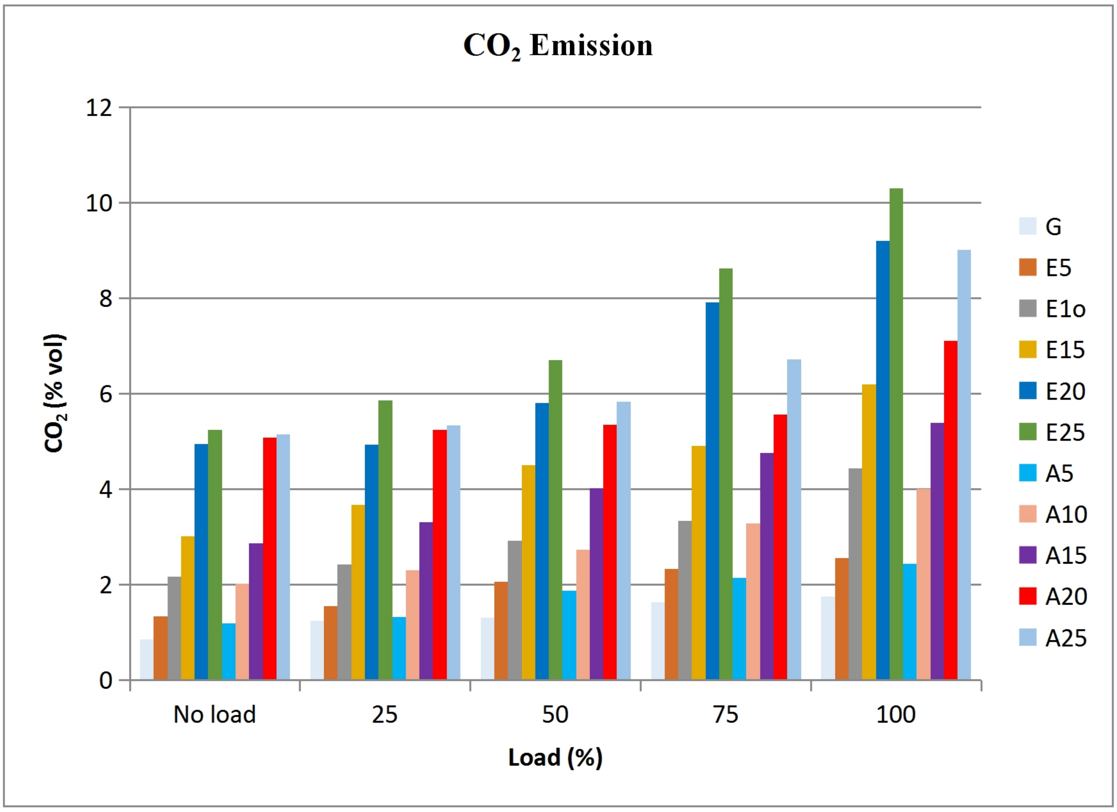


Figure 5-6. CO_2 Emission @ constant Speed and Variable Load

Figure 5-6. Since CO_2 is the byproduct of complete combustion, its emission noticed in this study as expected is increased as the engine load is increased for all test fuels as shown in the figure below. Also as discussed above bio-fuels are highly oxygenated (have high oxygen content) and contains lower carbon to hydrogen ratio which results in improving the combustion behavior of the fuels. Thus increases the CO_2 emission of the test engine. Among all the tested fuels, E20, E25, A20 and A25 registered the maximum and nearly similar CO_2 emission at full load as presented in the figure below. This indicates the addition of either purified (fractionally distilled) Arekie or ethanol has improved the combustion characteristics of the fuel and resulted more complete combustion compared to pure gasoline. ***Refer table 5-7 in appendix 3 for full CO_2 emission results.***

5.3.3. Unburnt Hydro carbons (UHC)

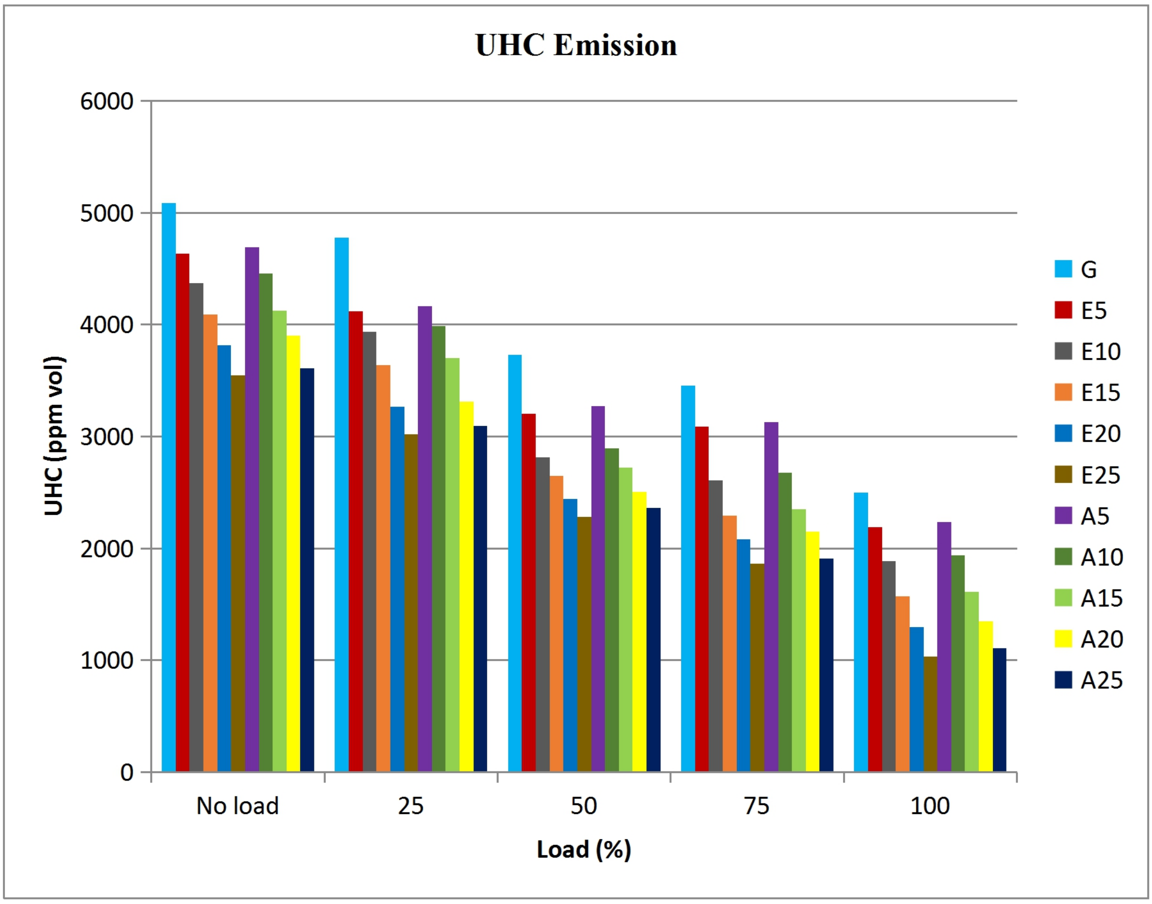


Figure 5-7. UHC Emission @ constant Speed and Variable Load

Figure 5-7. As blending gasoline with Arekie or ethanol improved the combustion characteristics of the test fuels and increasing load raised the combustion temperature which resulted the completeness of the combustion process, the possibility that we could have UHC as a byproduct of the combustion is too much reduced for the engine running with ethanol-gasoline or Arekie-gasoline blends compared to that running with regular gasoline. According to this study UHC emission of the test engine running with neat gasoline is improved about 49.15% because of the variation of load from 0% (no load) to 100% (full load). Among the blended fuels, E25 has shown less UHC emission followed by A25. ***Refer table 5-8 in appendix 3 for full UHC emission results.***

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

In this research work Ethiopian locally produced alcohol (Arekie) is introduced as an alternative fuel in blended form with a neat gasoline in S.I engine. Homemade Arekie was purchased from local producer and purified using fractional distillation and blended with gasoline in smaller proportions starting from 5 %v/v up to 25 %v/v in fraction of 5% (i.e. A5, A10, A15, A20, A25). Similarly an absolute ethanol was purchased from local supplier and blended with gasoline in similar way as Arekie (i.e. A5, A10, A15, A20, A25). Then a comparative investigation of performance and emission characteristics of the test engine was studied by conducting an experiment on a single cylinder spark ignition engine running at constant speed of 2500 rpm and variable loads. Pure gasoline (E0, A0) was taken as a baseline experiment or reference to compare the performance and emission characteristics of the engine running with blends of ethanol and blends of locally produced Arekie.

Based on the experimental results E20 provided the best result among all the tested fuels followed by A20. The engine generated maximum brake power (Pb) of 1.62 KW running with E20 and 1.6 KW running with A20 at full load. which is 5.88% and 4.57% greater compared to that of 1.53 KW generated running with pure gasoline at the same operating condition. Brake torque (Tb) also was much improved comparing the 5.73 Nm generated by running the engine with neat gasoline to 6.188 Nm and 6.11 Nm generated running with E20 and A20. The improvement is around 7.993% with E20 and 6.63% with A20. BSFC is another important characteristics improved by the addition of ethanol and/or Arekie in gasoline. It was improved by about 13.2% and 10.4% running the engine with E20 and A20 respectively instead of gasoline. The combined effect of those performance parameters, i.e. increased Pb, increased Tb and reduced BSFC with the increment of ethanol and/or Arekie in the fuel caused the BTE to improve. Hence the maximum brake thermal efficiency of 32.78% is achieved running the engine with E20 at constant speed of 2500 rpm and full load. The efficiency achieved operating with A20 (30.73%) was less compared to E20 but much efficient compared to the efficiency exhibited running with pure gasoline which is 26% at exact same operating condition.

Additionally, the increased proportion of ethanol and/or Arekie in pure gasoline resulted in reduction of CO and UHC emissions and increment in CO_2 emission because of the complete combustion. As the concentration of ethanol and/or Arekie increased up to 20 %v/v (E20, A20) in pure gasoline, the CO emission is reduced up to 75.849% and 65.65% running the engine with E20 and A20 respectively. For the similar operating conditions, the CO_2 emission was increased about 80.869% with E20 and 75.26 with A20. The increment of CO_2 emission was resulted because of the improved combustion characteristics of the fuels as oxygenated ethanol and Arekie are added to gasoline. As a result of this improvement, the UHC emission of the engine is reduced by the increment of added proportion of ethanol and Arekie in pure gasoline fuel at all operating conditions.

Thus E25 followed by A25 provided maximum reduction in UHC emission. E25 reduced 58.56% and A25 reduced 55.68% of the UHC compared to that released running with gasoline at similar operating conditions. But here the emission results of E20 and A20 are chosen to compare with the emission results of gasoline because of their better performance characteristics and comparative emission characteristics to that of E25 and A25. so the reduction of UHC emission caused by E20 was around 48.08% and that caused by A20 was around 46.16%. Generally, the addition of Ethiopian locally produced alcohol (Arekie) in pure gasoline has shown a significant improvement in the performance and emission characteristics of the test engine. A20 provided a less but comparative performance and emission results compared to E20, but much improved compared to that of pure gasoline. Hence we can say Arekie-gasoline blends can be considered as an alternative fuel to use in spark ignition engine.

6.2. Recommendations

This study is intended to introduce Ethiopian locally produced alcohol (Arekie) as an alternative fuel in the blended form. But the purification process followed here is only fractional distillation so that the physio-chemical properties did not match with absolute ethanol. Also some physical properties like octane number, dynamic and kinematic viscosities, flammability limit and flash point were not quantified. This makes our conclusion dependent on final results only. Before commercialization those properties has to be quantified to make scientific conclusions and some additional purification techniques has to be applied to match the properties with absolute ethanol. In addition this study did not include the effects of some variable operating conditions like: - compression ratio, engine speed, in-cylinder pressure, etc. and corrosion of components as a result of alcohol fuels are not considered. Therefore, those un-included topics should be studied further to use Arekie as alternative fuel.

6.3. Future Work

- The life expectancy of the engine operating with alcohol blended fuels can be optimized.
- The effects of varying CR, in-cylinder pressure, operating temperature, engine speed etc. can be studied.
- Effect of using alcohol fuels on engine components like corrosion can be investigated.

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Appendix 1

1. Software formula

Braking power PB in kW: In software CT 110 called: **P_{mech}**

$$Pb = 2 \,.\, \pi \,.\, Mb.\, n.\, \frac{1}{60} . \frac{1}{1000}$$

Where: MB: Braking torque in Nm

n: Engine speed in $\frac{1}{min}$

Fuel consumption $\dot{B}$ in $\frac{kg}{h}$**:** In software CT 110 called: **cons.**

$$\dot{B} = \frac{\Delta m}{\Delta t} . 36$$

Where: Δm in g

Δt in s

Specific fuel consumption b_e in $\frac{g}{kWh}$: In software CT 110 called: **spec.cons.**

$$be = \frac{\dot{B}.1000}{Pb}$$

Where: $\dot{B}\ in\ \frac{kg}{h}$

Pb in KW

Efficiency η_e in %: In software CT 110 called**: efficiency**

$$\eta e = \frac{Pb.3600}{\dot{B}.Hu} . 100$$

Thermal Power H_u in $\frac{kg}{kg}$: In software CT 110 called: therm.power

$H_u = 43500\ \frac{kj}{kg}$ (regular petrol)

$H_u = 43000\ \frac{kj}{kg}$ (diesel fuel)

$H_u = 43500\ \frac{kj}{kg}$ (mixture 1:50)

Volume flow intake air $\dot{V}_L$ in $\frac{m^3}{min}$: In software CT 110 called: dV/dt air

Calculation: ****************************

Air mass flow $\dot{m}_L\ in\ \frac{kg}{h}$:

$$\dot{m}_L = \dot{V}_L \cdot \rho \cdot \frac{T_0}{273.15 + \vartheta_L} \cdot \frac{P_L}{P_0} \cdot 60$$

where: : ρ Atmospheri cdensity atT_o in $\frac{kg}{m^3}$(= 1.275 $kg/_{m^3}$

T_o : Reference temperature in Kelvin 273.15K

L: Temperature intake air in °C

p_L : Atmospheric pressure in mbar

p_o: Reference pressure in mbar

Volumetric efficiency λ_L in % : In software CT 110 called: eta

$$\lambda_L = \frac{\dot{V}_L . 1000}{\dot{V}_{Hub} . n . 0.5} = \frac{m_z}{m_{th}} = \frac{\rho_z . V_h}{\rho_{air} . V_h}$$

Where: *VHub* : 1.4 ltr. diesel engine; 1.9 ltr. otto engine

n : Speed in $\frac{1}{min}$

0.5: Factor - four-cycle engine

m_z : Actual intake mass air flow

m_{th} : Theoretical air mass, which could be maximally in the cylinder, if the whole cylinder-volume was filled with fresh air.

a : Air density at the pressure and temperature of the surrounding air.

z : Density of the fresh air charge in the cylinder.

Air ratio λ : In software CT 110 called: lambda

$$\lambda = \frac{\dot{m}_L}{\dot{B}\,.\,L_{min}} = \frac{\text{L}}{L_{min}}$$

Where: L: Real intake air

L_{min}: Required Air, Minimum required intake air for fuel combustion Specification e.g. in kg air per kg fuel

L_{min} = 14.8 (regular petrol)

L_{min} = 14.5 (diesel fuel)

L_{min} = 14.8 (mixture 1:50)

Appendix 2

Table 5-2. Generated Brake Torque @ 2500rpm and Variable Load

Load (%)	Tb (Nm)										
	G	E5	E10	E15	E20	E25	A5	A10	A15	A20	A25
25	5.42	5.53	5.54	5.65	5.84	5.68	5.49	5.54	5.59	5.76	5.65
50	5.55	5.57	5.6	5.67	5.93	5.77	5.56	5.58	5.65	5.80	5.72
75	5.63	5.69	5.77	5.81	6.04	5.84	5.66	5.74	5.79	5.92	5.79
100	5.73	5.84	5.89	6.04	6.19	6.09	5.80	5.87	5.96	6.11	6.07

Table 5-3. Generated Brake Power @ 2500 rpm and variable load

Load (%)	**Pb (KW)**										
	G	E5	E10	E15	E20	E25	A5	A10	A15	A20	A25
25	1.448	1.448	1.45	1.48	1.53	1.486	1.437	1.45	1.464	1.508	1.48
50	1.459	1.459	1.47	1.485	1.552	1.51	1.456	1.462	1.48	1.52	1.498
75	1.49	1.49	1.51	1.52	1.58	1.53	1.481	1.504	1.518	1.55	1.518
100	1.53	1.53	1.542	1.58	1.62	1.595	1.519	1.538	1.56	1.6	1.59

Table 5-4. Brake Specific Fuel Consumption @ 2500rpm and Variable Load

Load (%)	**BSFC (g/kWh)**										
	G	E5	E10	E15	E20	E25	A5	A10	A15	A20	A25
25	404.7	399.4	391	387.1	367.54	381.2	402.351	396.82	387.4	370.4	385.037
50	377	371	364.2	360.5	332.65	352.5	374.441	367.261	362.2	336.17	356.84
75	333	329	326.2	320.2	300.02	315.12	331.71	328	323.5	308.82	317.58
100	313	306.8	300	291	271.68	285.25	309.82	302.21	295.1	280.42	288.26

Table 5-5. Brake Thermal Efficiency @ 2500rpm and Variable Load

Load (%)	**η_{th} (%)**										
	G	E5	E10	E15	E20	E25	A5	A10	A15	A20	A25
25	20.1	20.87	21.82	22.56	24.24	23.9	20.72	21.1	21.9	23.26	22.7
50	21.6	22.47	23.44	24.22	26.78	25.8	22.06	22.8	23.45	25.63	24.5
75	24.5	25.35	26.16	27.26	29.68	28.9	24.89	25.5	26.25	27.9	27.53
100	26	27.17	28.45	30	32.78	31.9	26.65	27.7	28.78	30.73	30.33

Appendix 3

Table 5-6. CO Emission @ 2500 rpm and under variable loading conditions

Load (%)	CO(%vol)										
	G	E5	E10	E15	E20	E25	A5	A10	A15	A20	A25
No load	8.6	4.694	4.255	3.68	2.25	0.93	5.56	5.31	3.92	2.942	1.441
25	5.275	4.257	4.189	2.74	2.17	0.63	5.08	4.512	3.074	2.381	1.217
50	4.462	3.681	3.241	2.22	1.72	0.28	3.90	3.394	2.547	2.068	1.091
75	3.891	2.741	2.19	1.18	0.98	0.25	3.24	2.548	1.718	1.514	0.824
100	3.238	2.215	1.684	1.01	0.78	0.20	2.68	2.028	1.542	1.112	0.754

Table -5-7. CO_2 Emission @2500 rpm and under variable loading conditions

Load (%)	CO_2 (%vol)										
	G	E5	E10	E15	E20	E25	A5	A10	A15	A20	A25
No load	0.86	1.34	2.17	3.02	4.95	5.24	1.19	2.03	2.87	5.09	5.15
25	1.24	1.55	2.43	3.67	4.93	5.86	1.32	2.31	3.314	5.24	5.332
50	1.31	2.07	2.92	4.51	5.81	6.71	1.87	2.74	4.018	5.35	5.84
75	1.64	2.33	3.34	4.91	7.92	8.62	2.14	3.29	4.76	5.56	6.72
100	1.76	2.56	4.44	6.20	9.2	10.3	2.44	4.01	5.39	7.114	9.02

Table -5-8. UHC Emission @ 2500 rpm and under variable loading conditions

Load (%)	**UHC (ppm vol)**										
	G	E5	E10	E15	E20	E25	A5	A10	A15	A20	A25
No load	5086	4635	4371	4092	3816	3548	4694	4457	4126	3901	3612
25	4775	4121	3937	3638	3264	3018	4164	3986	3702	3312	3093
50	3729	3205	2816	2648	2441	2282	3275	2896	2721	2504	2361
75	3456	3091	2608	2294	2084	1864	3131	2676	2352	2152	1910
100	2500	2193	1886	1574	1298	1036	2236	1941	1612	1346	1108