ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY
School of Chemical, Mechanical and Materials Engineering

PERFORMANCE TESTING OF SI ENGINE FUELLED WITH GASOLINE-ETHANOL BLEND AND LPG.

A Thesis Submitted in Partial Fulfillment of the Requirements for the award of the Degree of Master of Science in Automotive Technology Teachers Education

By

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Adama, Ethiopia

Candidates' declaration

We hereby declare that this project entitled "performance testing of SI engine fuelled with Gasoline- Ethanol blend and LPG in partial fulfillment of the requirement for the award of the degree of master of science in Automotive Technology Teacher Education is an authentic record of our own work carried out from March 2015 to May 2015 under the supervision of N. Ramesh Babu (Associate professor) Department of Mechanical and Vehicle Engineering, Adama Science and Technology University. The matter embodied in this paper has not been submitted for the award of any other degree or diploma. All the relevant sources of information used in this paper have been duly acknowledged.

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This is to certify that the above statement made by the candidates is correct to the best of our knowledge and belief. This project has been submitted for examination with our approval.

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Above all, praise is to *GOD* who privileged us actualize this prodigious task.

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List of acronyms, abbreviations and symbols

ACGIH	American Council of Governmental Industrial Hygienists
ADM	Archer Daniels Midland
A/F	Air- fuel mixture
Approx.	Approximately
ATDC	After Top Dead C enter
a.r	Back axle ratio
BBDC	Before Bottom Dead Center
BTDC	Before Top Dead Center
Birr/km	Birr per kilo meter
BSFC	Brake Specific Fuel Consumption
C	Carbon
CO	Carbon monoxide
C- O- H or C- OH	Alcohol
CO_2	Carbon dioxide
CH_4	Methane
C_2H_4	Ethane
C_2H_5OH	Ethanol
C_3H_8	Propane
C_4H_{10}	n- butane or Isobutene
C_5H_{12}	n- pentane, Iso-pentane or Neopentane
C_6H_{14}	n-Hexane
C_2H_4	Ethylene
C_3H_6	Propylene
C_4H_8	n-Butene
CI	Compression ignition
CNG	Compressed Natural Gas
C_R	Driving wheel circumference
DDC	Detroit Diesel Company
E00	Zero percent ethanol/ without ethanol blend
E10	10 percent ethanol blend
E20	20 percent ethanol blend
E30	30 percent ethanol blend
E40	40 percent ethanol blend
E50	50 percent ethanol blend
E60	60 percent ethanol blend
E70	70 percent ethanol blend
E80	80 percent ethanol blend
E85	85 percent ethanol blend
E90	90 percent ethanol blend
E100	pure ethanol
EPA	Environmental protection agency
F	Tractive effort
gm/hr	Gram per hour

gm/ km	Gram per kilo meter
gm/ kwhr	Gram per kilo watt hour
gm/ sec	Gram per second

GPRE	Green Plains
g.r	Gearbox gear ratio
H_2	Hydrogen
H_2O	Water
HC	Hydrocarbon
HHV	Higher heating value
IC	Internal combustion
Km/hr	Kilo meter per hour
Kgf.m	Kilo gram force meter
Kg/ k mol	Kilo gram per kilo mole
Kg/ L	Kilo gram per liter
KJ/ Kg	Kilo joule per kilo gram
KN	Kilo Newton
KPa	Kilo pascal
KW	Kilo Watt
LHV	Lower heating value
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
M	Meter
m^3	Meter cube
Mbar	Milli bar
$\dot{m}_f$	Mass flow rate
Mm	Milli meter
M/S	Meter per second
MJ/kg	Mega joules per kilo gram
MJ/L	Mega joule per liter
MPa	Mega pascal
MTBE	Methyl tert- butyl ether
N	Engine speed
N_2	Nitrogen
NG	Natural Gas
NGL	Natural Gas Liquid
Nm	Newton meter
NO	Nitric oxide
NO_X	Nitrogen oxide
O_2	Oxygen
OEMs	Original equipment manufacturers
P	Power
P_b	Brake Power
p_w	Power at the wheels

PPM	Percentage per minute
Psi	Pounds per square inch
Q_{LHV}	Lower calorific value
R	Radius of tire

RFG	Reformulated Gasoline
RPM	Revolution Per Minute
RVP	Reid Vapor Pressure
SFC	Specific Fuel Consumption
SI	Spark ignition
SO_2	Sulfur dioxide
T_b	Brake torque
T_e	Engine Torque
T_W	Torque at rear wheels
THC	Total hydrocarbon
V	Vehicle speed
VLO	Valero
VOL	Volume
η_{bt}	Brake thermal efficiency
η_t	Overall transmission efficiency

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ABSTRACT

Alternative fuels for both spark ignition and compression ignition engines have become very important owing to increased environmental protection concern, the need to reduce dependency on petroleum and even socioeconomic aspects. The primary objective of this study is to test the performance of a 4 cylinder 4 stroke SI engine fuelled with 10% Ethanol-90% Gasoline blend and LPG. The significance of this study is that helps to understand the performance of spark ignition engine when fuelled with Gasoline- Ethanol blend and LPG, Contribute to the current body of literature regarding use of Gasoline- Ethanol blend and LPG fuels in IC engines and Can be useful for several researches to come. In this study the engine with compression ratio 9:1 is tested using Gasoline- Ethanol blend and LPG by varying engine speed. Performance tests are conducted for brake torque, brake power, brake specific fuel consumption and brake thermal efficiency using a chassis dynamometer. Emission tests have verified that when the engine is fuelled with LPG the concentration levels of CO and HC are found to be lower than Gasoline- Ethanol blend. LPG is found to be cleaner than Gasoline- Ethanol blend. LPG has shown 23.51% reduction in brake torque on average, but LPG has also registered 6.52% torque reduction in medium speeds. The torque performance characteristics have shown that LPG performs comparably as well as Gasoline- Ethanol blend in medium speed ranges. On average LPG shows a 38.125% reduction in brake power. However, at lower vehicle speeds the brake power reduction is comparatively small. For example, when the vehicle is driven at 30km/hr on 4th gear, the brake power reduction is only 4.41%. Based on the brake power performance characteristics LPG is a good alternative for vehicles that are mostly driven within city speed limits. The brake specific fuel consumption (bsfc) results show that the performance of LPG is better than Gasoline- Ethanol blend. Although LPG was found to have the largest brake thermal efficiency of 36%, its average brake thermal efficiency is 25.5%. Gasoline- Ethanol blend on the other hand has a maximum brake thermal efficiency of 43% and average brake thermal efficiency of 31%. The results show that the performance and Emission characteristics of the LPG- fuelled engine are well suited for stationary engines such as generators and water pumps operating in medium speed range. Vehicles such as taxis, school transport vehicles, automobiles operating in towns and other vehicles which are mostly driven at high speeds in the vicinity of 30km/hr are better fuelled with LPG. If such vehicles are converted to run on LPG, they can provide a comparable power with the least of Emission.

Key words: liquefied petroleum gas, brake torque, brake power, brake specific fuel consumption, thermal efficiency

CHAPTER ONE
INTRODUCTION

1.1 Background of the study

It is the dream of engineers and scientists to develop engines and fuels such that very few quantity of harmful emissions are generated and these could be let into the surroundings without a major impact on the environment. Air pollution is predominately emitted through the exhaust of motor vehicles and the combustion of fossil fuels. Government around the world has set forth many regulatory laws to control the emissions. The growing sector of transports, rise a big alarm either for the day-by-day increasing number of vehicles and for the sensible contribution to the degradation of air quality in urban areas, as well as for the global pollution. Due to high thermal efficiency and power density, IC engines are widely used for transportation and stationary power source [3].

IC engines exhaust emissions, due to stringent emission norms caused engine manufacturer to examine the potential of alternative fuels. CO_2 reduction in mobility sector is a major challenge for next decade. 30 billion tons of CO_2 is added to atmosphere every year by the entire nation. One of the serious problems facing the modern technological society is the drastic increase in environmental pollution by Internal Combustion engines (IC engines). All transport vehicles with SI and CI (compression ignition) engines are equally responsible for the emitting different kinds of pollutants. Some of these are primary kinds having direct hazardous effect such as carbon monoxide, hydrocarbons, and nitrogen oxides while others are secondary pollutants such as ozone, which undergo a series of reactions in the atmosphere and become hazardous to health. The emissions exhausted into the surroundings pollute the atmosphere and cause global warming, acid rain, smog, odours and respiratory and other health hazards. The urgent need for alternative fuel is essential to replace the supplement conventional fuels. A pollutant is a component which changes the balance of environment and nature under normal condition. The major exhaust emissions HC, CO, NO_x, SO_2, solid particles are and performance is increased by adding the suitable additives to the fuel reduced with the present technology [7].

It is therefore the aim of this research is to “performance testing of SI engine fuelled with Gasoline- ethanol blend and LPG.” The engine performance will be evaluated by running the test vehicle on a chassis dynamometer.

In the present study, to reduce the emissions and to improve the performance of spark ignition engine, the modification technique is used (applied for LPG fuel system). The study evaluates the performance of a four cylinder spark ignition engine when fuelled with Gasoline-ethanol blend and LPG. Experimental investigation of LPG fuelled spark ignition (SI) engine will be done and the results thus obtained will be compared to the results obtained from experimenting with Gasoline-ethanol blend [9].

1.2 Statement of the Problem

This research is dedicated to finding alternative fuel to SI engines, and in doing so it was answered many questions related to Gasoline-ethanol blend and LPG as a fuel. In compliance with the research question and the problem statement, the analysis and experimentation was done on a four-stroke four cylinder spark ignition engine; and in so doing the following sub questions are addressed:

- How can a Gasoline engine be converted to a Gasoline- ethanol blend and LPG fuel engine?
- What are the performance characterstics of a four stroke SI engine when fuelled with Gasoline-ethanol blend & LPG and testing on chassis dynamometer?
- How will LPG fuelled engine performance compare to Gasoline-ethanol blend fueled engine performance?

1.3Objectives

1.3.1 General Objective

The general objective of this project is to test the performance of SI engine fuelled with Gasoline-Ethanol blend & LPG.

1.3.2 Specific objectives

In order to achieve the general objective, the following specific activities will be performed:

- To prepare test fuel blends.
- To modify the fuel system of Gasoline vehicle to use LPG.
- To conduct performance test on the Gasoline vehicle with Gasoline-ethanol blend.
- To conduct performance test on the Gasoline vehicle with LPG.
- To compare the test results.

1.4 Significance of the study

The research on the application of Gasoline-ethanol blend and LPG fuel in spark ignition engine has many relevancies; some of which are:

- Helps to understand the performance of spark ignition engine when fuelled with Gasoline-ethanol blend and LPG.
- Contribute to the current body of literature regarding use of Gasoline-ethanol blend and LPG fuels in IC engines.
- Can be useful for several researches to come. Those who would like to investigate the effect of using Gasoline-ethanol blend and LPG based fuel on engine parts, the performance of Gasoline-ethanol blend and LPG fueled engines, the emission characteristics of Gasoline-ethanol blend and LPG fueled engines, the effects of Gasoline-ethanol blend and LPG fueling on engine cooling and lubrication, etc, can use the research findings.

1.5 Delimitation (Scope) of the study

The result of this project would be more full fruit if it includes all. However, Covering all spark ignition (SI) engines in this research is practically unattainable thus, We would like to limit the project only to perform the test on a vehicle equipped with four cylinder, four stroke, water cooled, carbureted, spark ignition engine with conventional contact point ignition system.

1.6 Limitation of the study

The extremely poor research facility found at the automotive technology work shop of Adama science and Technology University is believed to have affected negatively the research finding. The fact that the equipment and instrument found in the workshop are not up-to-date will pose a question as to their accuracy. There were also challenges associated with the difficulty of finding appropriate manuals for the instrument and devices used in the research.

Unavailability of flow measuring device for measuring LPG fuel consumption and air mass consumed was one of the challenges. The exhaust gas analyzer that was available for the research measured only CO and HC emission and therefore it was not possible to measure other exhaust emission product such as NO_x.

1.7 Organization of the study

On successful completion, this thesis tried to show one way of answering today's ever increasing demand of alternative energy; this is the use of LPG and Gasoline- ethanol blend fuel as a fuel to power Gasoline engine. A vehicle with carbureted 4 cylinders, 4 stroke gasoline engine was selected for the study. Having installed LPG and Gasoline- ethanol blend fuel system, the performance characteristics of the engine were investigated by running the test vehicle on a dynamometer.

The first part of the research was concerned with performance testing of the SI engine powered with Gasoline- ethanol blend. Once the items necessary for the LPG fuel system have been secured and installed same engine was tested for its performance with LPG. Conclusion is drawn from comparison of thus obtained test results.

CHAPTER TWO

LITERATURE REVIEW

2.1 Historical background of Gasoline- Ethanol blend and LPG

In 1910, under the direction of Dr. Walter Snelling, the U.S. Bureau of Mines investigated gasoline to see why it evaporated so fast and discovered that the evaporating gases were propane, butane, and other light hydrocarbons. Dr. Snelling built a still that could separate the gasoline into its liquid and gaseous components and sold his propane patent to Frank Phillips, the founder of Phillips Petroleum Company.

By 1912, propane gas was applied for cooking food at home. The first car powered by propane ran in 1913. By 1915 people were using propane in torches to cut through metal. LPG has been used as a transportation fuel, mainly in heavy trucks and forklift vehicles, around the world for more than 60 years [2].

Ethanol is not a new fuel. In the 1850s, ethanol was a major lighting fuel in the United States. During the North American Civil War, a liquor tax was placed on ethanol to raise money for the war. The tax increased the price of ethanol such that it could no longer compete with other fuels, such as kerosene in lighting devices. Ethanol production declined sharply because of this tax and production levels did not begin to recover until the tax was repealed in 1906 [3].

In 1908, Henry Ford designed his Model T to run on a mixture of gasoline and alcohol, calling it “the fuel of the future.” In 1919, when Prohibition began, ethanol was banned because it was considered liquor. It could only be sold when it was mixed with petroleum. With the end of Prohibition in 1933, ethanol was used as a fuel again and its use increased temporarily during World War II when oil and other resources were scarce. In the 1970s, interest in ethanol as a transportation fuel was revived when embargoes by major oil producing countries cut petrol supplies. Since that time ethanol use has been encouraged by offering various tax benefits for producing ethanol and for blending ethanol into petrol [5].

In 1988, ethanol began to be added to petrol for the purpose of reducing carbon monoxide emissions in North America as ethanol is an oxygenate. Demand for ethanol increased when MTBE (an alternative oxygenate) was banned in 2000 due to the discovery of trace amounts of MTBE in the ground water [5].

Brazil was the world leader in fuel ethanol production and utilization until 2005. Since then the US has consistently produced more ethanol each year than Brazil. The Brazilians use sugar cane as the primary feedstock to produce up to 50% of the nation’s automotive fuel [8].

2.2 Composition and fuel description of Gasoline- Ethanol blend and LPG

LPG is any mixture of several hydrocarbon compounds that are gases at normal room temperatures and pressures but can be liquefied under moderate pressure at atmospheric temperatures. These gases can include, paraffin’s occurring between ethane (a gas) and pentane (a liquid) and Mon olefins occurring between ethane and pentene. The paraffin’s include propane, iso-butane, and butane. The Mon olefins include Propylene, isobutene, 1-butene, and 2-butene.

Varieties of LPG bought and sold in variety composition of propane and butane. The common composition of LPG contains 60% volume of propane and 40% volume of butane. However there have some variations of LPG composition as dictated by its Usages and applications. Commercial Propane predominantly consists of hydrocarbons containing three carbon atoms, mainly propane (C_3H_8).

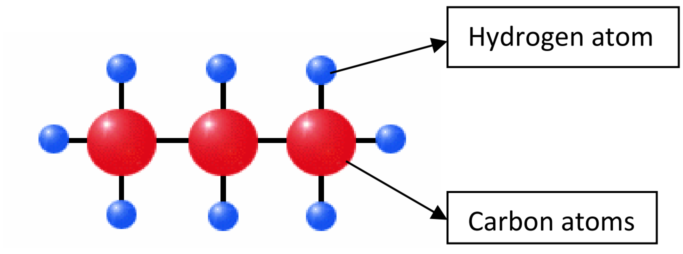

Figure 1: Atomic Structure of Propane

Commercial Butane predominantly consists of hydrocarbons containing four carbon atoms, mainly n- and iso-butanes (C_4H_{10}).

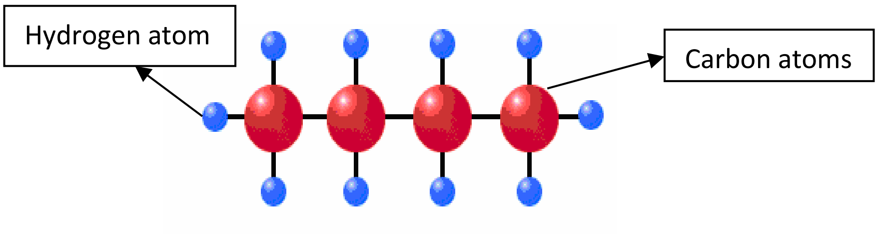

Figure 2: Atomic Structure of n-Butanes

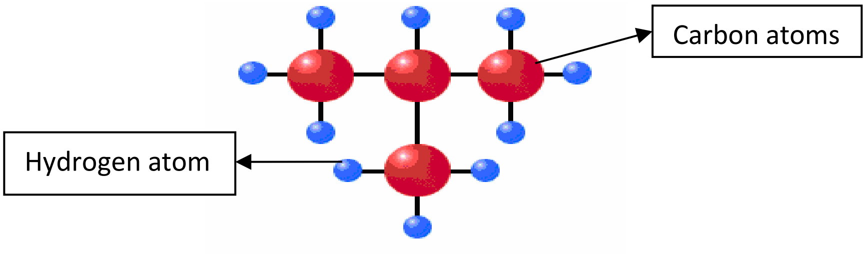

Figure 3: Atomic Structure of iso-Butanes

Propylene and butylene's are usually also present in small concentration. A powerful Odorant, ethanol, is added so that leaks can be detected easily [4].

Liquefied Petroleum Gas (LPG) is often incorrectly identified as propane; in reference to the mixture's chief ingredient. In fact LPG is a mixture of petroleum and natural gases that exist in a liquid state at ambient temperature when under moderate pressure (less than 13.78 bar). The common interchanging of the two terms is explained by the fact that in the U.S and Canada LPG consists primarily of propane (see Table 1). In many European countries, however, the propane content in LPG can be as low as 50% or less.

Table1: Composition of LPG (US HD-5 Standard)

Constituent	Percentage
Propane	85% min. by liquid volume
Propylene	5% max. by liquid volume
Butane and heaver HC	2.5% max. by liquid volume
Sulfur	120 ppm max. by weight

Liquefied petroleum gas is provided in pressurized bottles made of steel which are not filled completely to allow the gas to expand safely during storage. In some areas, especially the US, LPG is also referred to as Auto gas. LPG is a non- toxic, non-corrosive; lead-free gas and is produced by refinery fractionation of oil or is stripped from naturally occurring Natural Gas.

Ethanol, also known as Ethyl Alcohol, is a light volatile liquid. It is a member of the family of organic compounds collectively known as alcohols. The alcohols all contain a chain of carbon atoms surrounded by hydrogen atoms except for one bonding site, where the carbon atom is bonded to an oxygen atom, which in turn is bonded to a hydrogen atom (the combination of the oxygen atom and hydrogen atom is also referred to as a “hydroxyl group”). Alcohol is shown as: C-O-H or C-OH.

Ethanol is the member of the alcohol family that has two carbon atoms. Other members of the alcohols that are often associated with automotive fuel applications are: methanol (one carbon atom, also called “wood alcohol”), propanol (three carbon atoms, often familiar in the form of isopropyl alcohol, better known as “rubbing alcohol”) and butanol (or isobutanol).

$$\begin{array}{ccccccc} & & H & & H & & \\ & & | & & | & & \\ H & - & C & - & C & - & O - H \\ & & | & & | & & \\ & & H & & H & & \end{array} \quad \text{or} \quad CH_3CH_2OH$$

Fig 4: The chemical formula of ethanol.

And Gasoline is a mixture of hydrocarbons. The hydrocarbons are very similar, chemically, to the alcohols, except that the hydrocarbons do not contain any oxygen atoms. Ideal gasoline would be a single molecule with eight carbon atoms, or “octane”. In reality, gasoline is a blend of hydrocarbons containing between four and twelve carbon atoms [9].

2.3 Properties of Gasoline- ethanol blend and LPG

2.3.1 Physical properties

LPG at atmospheric pressure and temperature is a gas which is 1.5 to 2.0 times heavier than air, but it can be liquefied when moderate pressure is applied or when the temperature is sufficiently reduced. It can be easily condensed, packaged, stored and utilized, which makes it an ideal energy source for a wide range of applications.

Normally, the gas is stored in liquid form under pressure in a steel container, cylinder or tank. The pressure inside the container will depend on the type of LPG (commercial butane or commercial propane) and the outside temperature [2].

At normal temperatures and pressures, LPG will evaporate. Because of this, LPG is supplied in pressurized steel bottles. In order to allow for thermal expansion of the contained liquid, these bottles are not filled completely; typically, they are filled to between 80% and 85% of their capacity. The ratio between the volumes of the vaporized gas and the liquefied gas varies depending on composition, pressure and temperature, but is typically around 250:1.

The pressure at which gas becomes liquid, called its vapor pressure, likewise varies depending on composition and temperature; for example, it is approximately 220 KPa (2.2 bar) for pure butane at 20 °C (68 °F), and approximately 2.2 MPa (22 bar) for pure propane at 55 °C (131 °F).

The evaporation temperature is not the only parameter that influence on the evaporation of the propane butane mixture. The evaporation requires heat and if the heat transfer to the liquid gas is limited, the liquid will be under cooled and the evaporation reduced. Larger consumes requires in general heat exchangers fueled with hot water, electric heater or combustion of the propane butane mix itself. Smaller amounts of consumption require containers with efficient heat transfer. For example composite container provides less heat transfer compared with steel containers [3].

Gasoline is a hydrocarbon produced from crude oil by fractional distillation. It is non-water miscible (which makes it hydrophobic) and has a flash point of approximately -45°F, varying with octane rating. Gasoline has a vapor density between 3 and 4. Therefore, as with all products with a vapor density greater than1.0, gasoline vapors will seek low levels or remain close to ground level. Gasoline has a specific gravity of 0.72–0.76 which indicates it will float on top of water since it is non-water miscible or insoluble. Its auto-ignition temperature is between 536°F and 853°F, and it has a boiling point between 100°F and 400°F depending on fuel composition [1].

And pure Ethanol is a polar solvent that is water-soluble and has a 55°F flash point. Ethanol has a vapor density of 1.59, which indicates that it is heavier than air. Consequently, ethanol vapors do not rise, similar to vapors from gasoline, which seek lower altitudes. Ethanol's specific gravity is 0.79, which indicates it is lighter than water but since it is water-soluble (it be considered hydrophilic). it will thoroughly mix with water. Ethanol has an auto-ignition temperature of 793°F and a boiling point of 173°F. Ethanol is less toxic than gasoline or methanol. Carcinogenic compounds are not present in pure ethanol [5].

While blending ethanol with gasoline has multiple effects. Ethanol increases the heat output of the unleaded gasoline, which produces more complete combustion resulting in slightly lower emissions from unburned hydrocarbons. The higher the concentrations of ethanol, the more the fuel has polar solvent-type characteristics with corresponding effects on conducting fire suppression operations. However, even at high concentrations of ethanol, minimal amounts of water will draw the ethanol out of the blend away from the gasoline. Ethanol and gasoline are very similar in specific gravity. The two differing fuels mix readily with minimal agitation, but the blend is more of a suspension than a true solution.

Ethanol has a greater affinity for water than it does for gasoline. Over time, without agitation, gasoline will be found floating on a layer of an ethanol/water solution. The resulting ethanol/water solution is still flammable since the concentration of ethanol is still fairly rich. Phase separation can occur in fuel storage systems where water is known to be present.

Blending these fuels together alters the physical and chemical characteristics of the original fuels. However, the resulting changes may be unnoticeable to emergency responders however, because gasoline is used in the blend, E-85 is considered potentially carcinogenic. One of the noticeable differences in the blended fuel versus unblended gasoline is the visual difference of the smoke and flame characteristics. Higher concentrations of ethanol produce less black smoke and decreased visible flame color. These characteristics may be masked by other substrates that may also be burning such as vehicle tires. Another noticeable difference of ethanol-blended fuels under fire conditions is that when foam or water has been flowed on the burning product, the gasoline will tend to burn off first, eventually leaving the less volatile ethanol/water solution which may have no visible flame or smoke [8].

Table 2: Properties of gasoline fuel blended with various percentage of ethanol [8].

Sample code	Ethanol (%)	Gasoline (%)	Flash Point (^{0}c)	Auto ignition temperature (^{0}C)	Vapour pressure at (Kpa at 37.8^{0}C)	Energy density (MJ/L)	Octane number	Specific gravity
E00	00	100	-65	246	36	34.2	91	0.7474
E10	10	90	-40	260	38.9	33.182	93	0.7508
E20	20	80	-20	279	39	32	94	0.7605
E30	30	70	-15	281	38	31.5	95	0.7782
E40	40	60	-13.5	294	35.6	30	97	0.7792
E50	50	50	-5.0	320	34	29	99	0.7805
E60	60	40	-1.0	345	31	28	100	0.7812
E70	70	30	0.0	350	28	27	103	0.7823
E80	80	20	5.0	362	24	26.5	104	0.7834
E90	90	10	8.5	360	18	23.6	106	0.7840
E100	100	00	12.5	365	9	23.5	129	0.7890

The oxygen in ethanol enhances the combustion process and reduces hydro carbon (HC) and carbon monoxide (CO) emissions. The standard for the oxygenate content in gasoline is set on a weight basis, as can be seen in Table 3.

Table 3: Ethanol content and oxygenate content in fuels.

Fuel ethanol content, volume %	Fuel Oxygen Content, weight %
5.7	2.0
7.7	2.7
10	3.5

Since there are differences in the density of different grades of gasoline compared to the density of ethanol the final content of oxygen will vary if the blending volume is fixed to a certain volume [10].

2.3.2 Energy content (calorific value)

The calorific value or heat of combustion or heating value of a fuel is the quantity of heat produced by its combustion at constant pressure and under conditions known as normal of temperature and pressure (to 0°c and under a pressure of 1,013 bar). The combustion of a fuel product generates water vapor. Certain techniques are used to recover the quantity of heat contained in this water vapor by condensing it.

It is usually expressed in Gross Calorific Value (GCV) or Higher Heating Value (HHV) and Net Calorific Value (NCV) or Lower Calorific Value (LHV).

The higher heating value (HHV, also known as gross calorific value or gross energy) of a fuel is defined as the amount of heat released by a specified quantity (initially at 25°c) once it is combusted and the products have returned to a temperature of 25°c. The higher heating value takes in to account the latent heat of vaporization of water in the combustion products, and is useful in calculating heating values for fuels where condensation of the reaction products is practical.

The lower heating value (also known as net calorific value or LHV) of a fuel is defined as the amount of heat released by combusting a specified quantity (initially at 25°c or another reference state) and returning the temperature of the combustion products to 150 °c. The lower heating value assumes the latent heat of vaporization of water in the fuel and the reaction products is not recovered. It is useful in comparing fuels where condensation of the combustion products is impractical, or heat at temperature below 150 °c cannot be put to use.

The Gross Calorific Values for most common gaseous fuels can be found in the table 4. Gross Calorific Values are commonly used in energy calculations in the United States.

Table 4: Gross Calorific value of most common fuels [1]

Fuel	Symbol	Gross calorific value (kJ/kg)
Carbon	C	32,780.32
Hydrogen	H_2	142,106.97
Carbon monoxide	CO	10,111.12
Methane	CH4	55,533.25
Ethane	C2H4	51,923.29
Propane	C3H8	50,402.09
n- butane	C4H10	49,592.65
Isobutene	C4H10	49,476.35
n- pentane	C5H12	49,066.97
Iso-pentane	C5H12	48,955.32
Neopentane	C5H12	48,794.83
n-Hexane	C6H14	48,766.92
Ethylene	C2H4	50,325.34
Propylene	C3H6	48,957.65
n-Butene	C4H8	48,506.40

While there is a degree of natural variation in heating values due to the specific proportions of propane and butane within a particular sample of LPG, it nevertheless has a comparably high heating value meaning it contain more energy per kilogram that most competing fuels.

Energy content and high heating value (HHV) varies significantly depending on the source of the fuel and its composition. The LPG energy content (High Heating Value, HHV) is 46.23 MJ/Kg

LPG has relatively high energy content per unit of mass, but its energy content per unit volume is low. Thus, LPG tank have more space and weight than petrol or diesel fuel tank, but the range of LPG vehicles is equivalent to that of petrol vehicles [12].

The calorific value of LPG that contains more butane is higher than one contains more propane. Since ethanol has a significantly lower energy value than gasoline its addition may affect the engine's power even though the octane number of ethanol is higher than that of gasoline. The engine's power output depends on the energy content per unit volume fuel injected into its combustion chamber. The reduction in energy content per unit volume fuel caused by adding different percentages of Ethanol to a certain blend of Gasoline.

An addition of 10 to 15 % ethanol to Gasoline will, to a certain degree, increase fuel consumption. As the energy content (MJ/L) of Gasoline- ethanol blends is lower than that of pure Gasoline the fuel consumption will most likely increase for the average driver [13]. The calorific value comparative properties of LPG, Ethanol and Gasoline fuels can be found in the table 5.

Table 5: Thermodynamics properties of LPG, Ethanol and Gasoline.

Characteristics	LPG	Ethanol	Gasoline
chemical formula	C_3H_8	C_2H_5OH	C_4 toC_{12}
Boiling point(°C)	-44	78	30-225
Molecular Weight (Kg/Kmol)	44.1	46.07	114.2
Density at 15°C (Kg/l)	0.53	0.79	0.7372
Research octane number	105	108.6	96-98
Stoichiometric air fuel ratio	15.6	9	14.7
Flame speed (m/s)	48	----	52.58
Upper flammability limits in air (%vol)	74.5	19	7.6
Lower flammability limits in air (%vol)	4.1	4.3	1.3
Calorific value (KJ/Kg)	46100	27000	43000

2.3.3 Octane rating

The "octane rating" of a motor fuel is an index of the fuel's ability to resist pre-ignition, or engine knock, and is based upon the anti-knock properties of pure octane being equal to 100. The Octane rating for LPG is very high compared to other fuels. (LPG has octane number of 110, regular- grade petrol has octane number of 92 and premium- grade petrol has octane number of 95).

The addition of butane slows down combustion speed in an engine, so that it reduces NO_x emission, while it increases emissions of total hydrocarbon (THC) and carbon monoxide (CO).

The LPG that contains higher number of hydrocarbon can give more quantity heat by its combustion but the flame speed from its combustion is slower and it also gives a higher effect to environment. The flame speed is decreasing when the composition of hydrocarbon is higher; in other word it decreases when the LPG contains more butane [6].

Since gasoline is inherently a blend of different hydrocarbons, which will ignite at different temperatures and pressures and burn at different rates, the octane rating of gasoline fuels is less than 100. Regular gasoline is the least refined (the greatest mixture of different hydrocarbons) and generally has an octane rating of around 86. Midrange and premium gasoline is more highly refined to contain a higher percentage of octane, raising their octane rating to around 92. While alcohol fuels do not contain any octane molecules, they can have a measurable octane rating. Pure ethanol has an octane rating of around 116. When blended with regular unleaded gasoline, ethanol boosts the fuel's overall octane rating [1].

2.4 Production of LPG and Ethanol

2.4.1 LPG production from natural gas processing

When gas is drawn from the earth, it is a mixture of several gases and liquids. Commercial natural gas is mainly composed of methane. However, it also contains ethane, propane and butane in accordance with the specifications for natural gas in each country in which it is distributed. Therefore, before natural gas is marketed, some NGLs, including LPG (propane and butane) are separated out, depending on the "wetness" of the gas produced: NGLs represent 1 to 10% of the unprocessed gas stream. Some NGLs are also trapped in crude oil. In order to stabilize the crude oil for pipeline or tanker distribution, these "associated" or

”natural gases” are further processed into LPG. Worldwide, gas processing is the source of approximately 60% of LPG produced.

2.4.2 LPG production from Crude oil (petroleum) refining

In an oil refinery, LPGs are produced at various stages: atmospheric distillation, reforming, cracking and others. The LPG produced will be between 1 and 4% of crude oil processed. This yield will depend on the type of crude oil, the degree of sophistication of the oil refinery and the market values of propane and butane compared to other oils products. Worldwide, refining is the source of approximately 40% of LPG produced. Like all other hydrocarbons obtained from oil and gas, LPG has its own distinct marketing advantages and can perform nearly every fuel function as the primary fuels from which it is derived. Furthermore, LPG supply is growing faster than any other oil products. As a result, demand for LPG is steadily growing throughout the world and forecasts show this trend will continue [1]. The figure 5 shown that the production and delivery process of LPG.

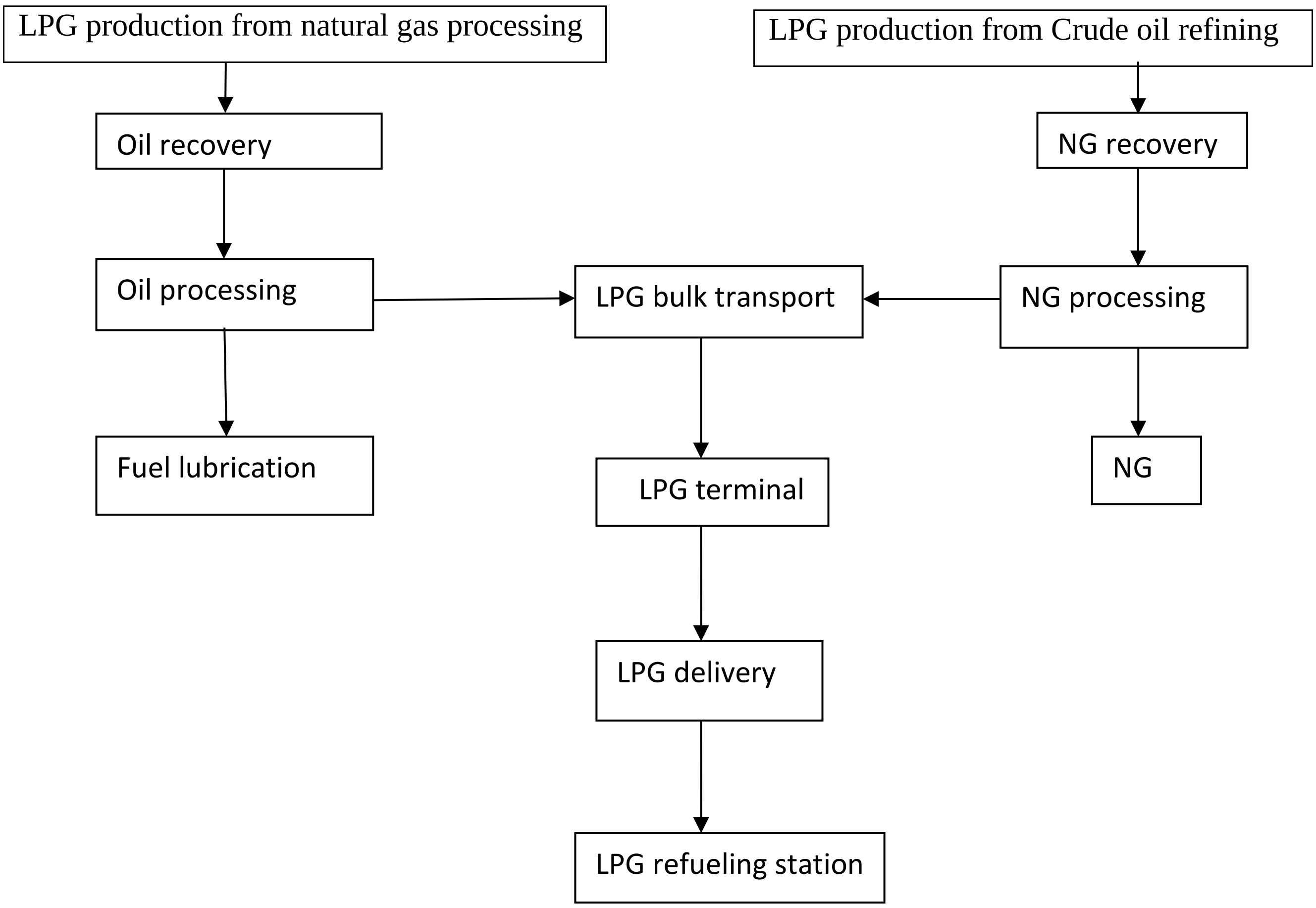

Figure 5: Schematic diagram of LPG production and delivery.

2.4.3 Ethanol fuel production from dry mill processing

Ethanol can be made by a dry mill process or a wet mill process. All of the new fuel ethanol plants in the U.S. use the dry mill method. The major steps in this process are:
Milling: The feedstock (corn, wheat, barley, etc.) passes through a hammer mill which grinds it into course flour called meal. The vast majority of ethanol in the U.S. is produced from corn.
Liquefaction: The meal is mixed with water and alpha-amylase enzyme to create a "mash" which is passed through cookers where the starch is liquefied. Heat is applied at this stage to enable liquefaction. Cookers with a high temperature stage (120-150 degrees Celsius) and a lower temperature holding period (95 degrees Celsius) are used. High temperatures reduce bacteria levels in the mash.

Saccharification: The mash from the cookers is cooled and the secondary enzyme (gluco-amylase) is added to convert the liquefied starch to fermentable sugars (dextrose).

Fermentation: Yeast is added to the mash to ferment the sugars to ethanol and carbon dioxide. Using a continuous process, the fermenting mash is allowed to flow through several fermenters until is it fully fermented and leaves the final tank. In a batch process, the mash stays in one fermenter for about 48 hours before it flows to the distillation process.

Distillation: The fermented mash, now called beer, contains about 15% alcohol plus all the non-fermentable solids from the corn and yeast cells. The beer is pumped to the continuous flow, multi-column distillation system where, using heat, the alcohol is removed from the solids and the water. In the final distillation column, the alcohol leaves the top of the final column at about 96% ethanol. The residue mash from the distillation process, called stillage, is transferred from the base of the first column to the co-product processing area.

Dehydration: The alcohol from the top of the last column passes through a dehydration system where the remaining water is removed. Most ethanol plants use a molecular sieve to capture the last bit of water in the ethanol. The alcohol product at this stage is called anhydrous ethanol (pure, without water) and is approximately 200 proof [7]. The major steps for this process are shown in the figure 6.

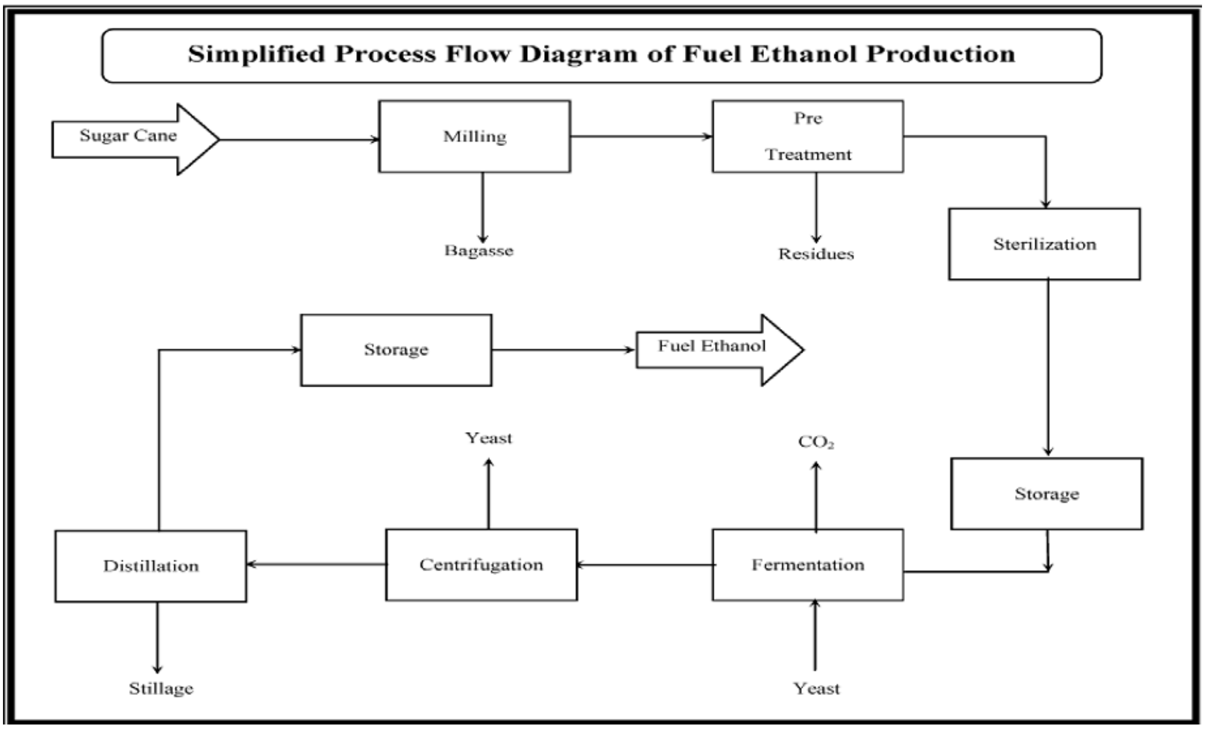

Figure 6: Simplified process flow diagram of fuel ethanol production.

2.5 Comparison of LPG and Gasoline-ethanol blend with petrol and diesel

2.5.1 Cold starting

Gaseous fuelled engine are generally considered easier to start than petrol or diesel engines in cold weather. Because the fuel is vaporized before injection into the engine the gaseous nature of the fuel/air mixture in an LPG vehicles combustion chamber eliminate the cold start problems associated with liquid fuels.

In contrast to Gasoline engines, which produce high emission levels while running cold, LPG engine emission remain similar weather the engine is cold or hot [10].

And high levels of an alcohol (over 20 %) usually adversely affect cold starts and warming up in low temperature conditions since more heat is needed to vaporize alcohol than Gasoline. Normally low levels, < 10 %, of alcohols in Gasoline do not cause problems during cold starts and the warming-up phase of the engine, especially for modern vehicles [12].

2.5.2 Engine life

Because LPG enters an engine's combustion chambers as a vapor. It does not strip oil from cylinder walls or dilute the oil when the engine is cold. This helps LPG powered engines to have a longer service life and reduced maintenance cost. The high octane rating and low carbon/oil contamination characteristics of LPG results in documented longer engine lifetime, up to twice that of the gasoline engines.

LPG helps promote longer vehicle life. The National Propane Gas Association of the USA reports that many fleets have experienced longer service life by two to three years as well as extended interval between required maintenance when using LPG. Spark plugs from an LPG engine can last two to three times longer than petrol engines. Like LPG, Gasoline- ethanol blend fuel helps promote longer vehicle life [2].

2.5.3 Pollution

LPG has the potential to reduce NO_x and hydrocarbon emissions when compared to gasoline or diesel fuel. Additionally, LPG produces low levels of particulate matter when compared to diesel fuel. Since LPG at ambient temperature and pressure is in the gaseous state, a spill will not result in significant localized contamination but will dissipate. Because of the compressed nature of the gas very little evaporative emissions are associated with LPG. Some venting occurs with fueling procedures in older LPG vehicle tanks [6].

And Ethanol blend is one of the best tools we have to fight air pollution. Ethanol blended engines have the potential to significantly reduce NO_x emissions compared to diesel fuel. However, NO_x emissions for the current DDC ethanol engine are not as low as those for the methanol configuration. This discrepancy could be due to engine tuning parameters. Ethanol blended engine emissions of formaldehyde and acetaldehyde can be controlled with catalytic converters. While ethanol is miscible with water and biodegrades quickly, spills are properly handled by collection and incineration [4].

2.5.4 Performance

LPG delivers roughly the same power, acceleration, and cruising speed characteristics as gasoline. It does yield a somewhat reduced driving range, however, because it contains only about 70-75%of the energy content of gasoline.

Its high octane rating means, though, that an LPG engine s power output and fuel efficiency can be increased beyond what would be possible with a gasoline engine without causing destructive knocking such fine –tuning can help compensate for the fuel s lower energy density [6].

Ethanol adds octane to Gasoline and improves engine performance. That means, using Gasoline-ethanol blends in practice is that blends with up to 15 percent ethanol will not have any significant negative effects on the wear of the engine or vehicle performance [4].

2.5.5 Cost

Fleet owners find that LPG cost are typically 5% to 30% less than those of gasoline. The cost of constructing an LPG fueling station is also similar to that of a comparably sized gasoline dispensing system.

LPG engines have cleaner combustion. Cleaner combustion means LPG engine last longer (commonly 30%longer) that petrol and often involve lower service costs that petrol or diesel engines these are important economic consideration. If the LPG used in a country is domestically produced LPG does help address the national security component of the nation’s overall petroleum dependency problem [6].

While the costs for ethanol blend fuel are higher than those of diesel fuel because of the fuel's price. Compared on an energy content basis to diesel fuel, ethanol blend fuel costs are more than twice as high, even when grain production is subsidized. The cost impact of new requirements for reformulated diesel fuel and tighter emission controls on diesels may reduce this cost difference in the future. Maintenance and fueling facility requirements for ethanol (and methanol) vehicles are similar to those of diesel, so no significant cost difference exists in these areas [4].

2.5.6 Noise

Due to their cleaner combustion, LPG and ethanol blended engines are, quieter than diesel engines, and marginally quieter than petrol engines [11].

2.5.7 Hot starting

Hot starting may produce difficulties .after an engine is shut down, the engine coolant continues absorb heat from the engine raising its temperature. If the vehicle is re-started within a critical period after shutdown (when both the coolant and the engine are at high temperature) then the coolant will heat the gas more than normal, lowering its volumetric heating value and density.

However, higher ethanol blends impacting hot drivability. The volatility of 5.7%10% ethanol blends is approximately 1 psi higher than unleaded gasoline unless a low-RVP base fuel is used. Vapor lock, and difficult hot start can potentially occur more often in a fuel with a higher volatility, particularly in summertime conditions. However, in current practice, manufacturers have already engineered solutions to this problem since E10 is so widely used in today's Gasoline market [3].

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2.5.8 Availability

LPG is supplied by independently owned and operated companies. Often one area is served by several independent companies that will work with customers to install fueling systems. LPG is
produced within the continental United States as a by-product of natural gas and oil production. It is also available from overseas locations via large ships. Net imports of LPG to the United States are approximately 9 percent of the total supply. The independent LPG companies introduce an odorant chemical into the gas to act as a leak indicator. This odorant should be present in any vehicular LPG [1].

And Ethanol is currently produced in the United States from corn and other grain products. Ethanol from sugar cane is imported from South America *(20).* Ethanol for transit bus fuel is generally obtained through the same distribution channels as those for ethanol as an additive to Gasoline. Ethanol is widely available in the Midwest, but in other parts of the country, availability depends on proximity to storage terminals [10].

2.6 Emissions benefits of LPG and Gasoline-ethanol blend fuel

The major harmful emissions from LPG and Gasoline-ethanol blend fuel engines are similar to those from other internal combustion engines:

- Carbon monoxide (CO)
- Hydrocarbons (HC)
- Nitrogen oxides (NO_x)

2.6.1 Carbon monoxide emission

Carbon monoxide is generated in the exhaust as the result of incomplete combustion of fuel. CO is a very toxic, colorless and odorless gas. LPG emissions may contain considerable amounts of CO. When engines operate in enclosed spaces, such as warehouses, buildings under construction, or tunnels, carbon monoxide can accumulate quickly and reach concentrations which are dangerous for humans. It causes headaches, lethargy, lethargy, and death. CO is usually the major concern whenever LPG engines are used indoors.

In comparison to most hydrocarbons, LPG has a low carbon to hydrogen ratio, which means that it generates lower amounts of carbon dioxide per amount of heat produced.

Emission of carbon monoxide is greatly dependent on the air fuel ration to the stoichiometric proportions. LPG stoichiometric A/F = 15.8. Rich mixture invariably produces more carbon monoxide (CO) and its emission increases nearly linearly with the deviation from the stoichiometry. Compared to gasoline, gasoline- ethanol blend produced lower CO emissions by 30 % [8].

By adding ethanol to Gasoline, which contains oxygen, combustion in the engine is more complete and CO is reduced. Research shows that reductions may reach as high as 30 percent depending on the type and age of the automobile, the emission system used, and the atmospheric conditions.

Maximum CO is generated when an engine runs rich, such as when starting or when accelerating under lead. Even when the intake air-fuel mixture is stoichiometric or lean, some CO will be generated in the engine. Poor mixing, local rich regions, and incomplete combustion will create some CO [12].

2.6.2 Hydrocarbons

Hydrocarbons are also a product of incomplete complete of fuel. LPG emissions, because of fuel composition. Contain only short chain hydrocarbons. They are not likely to contain toxic components which are found in gasoline HC emissions. Also, the environmental impact of LPG hydrocarbon emissions (ozone reactivity contributing to smog) is much smaller than that of gasoline. However, Hydrocarbon derivatives are responsible for the characteristic smell which is often a nuisance when LPG engines operate indoors [2].

However, when using gasoline/ethanol blends as fuel the uncombusted fuel constituents include
both unburned gasoline (which consists mainly of hydrocarbons as noted) and un combusted ethanol. Thus, the HC emissions measured in the diluted exhaust consist of both hydrocarbons
and ethanol (alcohol). The oxygen contained in ethanol blends (through ethanol) reduced HC emissions. However, the hydrous (ethanol with 7.8% by weight of water) ethanol blend produced higher HC emissions than the anhydrous (ethanol with 6.8% of water by volume) ethanol Gasoline blend. The values were still lower than those for Gasoline [7].

2.6.3 Nitrogen oxides

Nitrogen oxides are generated from nitrogen and oxygen under the high temperature and pressure conditions in the cylinder. NO_x Consists mostly of nitric oxide (No) and some nitrogen dioxide (NO_2). Nitrogen dioxide is a reactive gas, very toxic for humans. Accumulation of NO_x in a warehouse atmosphere may also be detrimental for the stored goods. For example, only a few ppm of NO_x in the ambient air can change the color of paper stock from white to yellowish. NO_x Emission is also a serious environmental concern because of their ozone reactivity and important role in smog formation.

LPG was introduced to the market as a “clean-burning “fuel. LPG definitely had the potential to become clean fuel. The reasons for the superior emissions performance of LPG were the following.

- Reduced emission of carbon monoxide compared to Gasoline engines (but not as low as in diesel engines)
- No heavy hydrocarbon emission. HC, which are emitted, are of short carbon chain and low ozone-forming reactivity.

- Low emission of air contaminants such as benzene and 1,3-butadiene
- Low cold-start emissions
- Likely better emission durability than of Gasoline engines. LPG emissions should not increase as dramatically with the engines wear and deposit build-up
- Zero evaporative and running losses due to the sealed fuel system.

NO_x contributes to ground level ozone (photochemical smog). Several components of Gasoline that impact NO_x emissions, including olefins and aromatics, are reduced by adding ethanol to Gasoline. Environmental Protection Agency (EPA) studies indicate the use of ethanol blends may slightly increase NO_x emissions under some conditions, but the extent and effects are uncertain.

Ethanol/gasoline blends when compared to gasoline, in general,

- increase the evaporative emissions,
- in exhaust they reduce CO, HC, and toxic emissions, increase aldehyde emissions, and may increase NO_x,
- On a life cycle basis they reduce carbon dioxide emissions; the amount of reduction depends on the type of feedstock and the ethanol production process.

Vehicle emission is a major source of air pollution especially in the urban area. To reduce pollution, many governments would encourage the use of cleaner alternative fuel [11].

2.6.4 Air toxics

LPG has very low 1,3 butadiene and benzene emissions, but aldehyde emissions increase substantially, as with alcohol fuels (compared to gasoline vehicles). However, these higher aldehyde emissions would likely be reduced with a catalyst specifically designed for an LPG vehicle. Compared to diesel vehicles LPG produces much lower emissions of the main air toxics such as benzene, 1,3 butadiene, formaldehyde and acetaldehyde [1].

Since ethanol is an alcohol, it does not produce hydrocarbons when being burned or during evaporation. Overall, the ozone forming potential of ethanol blends, which vaporize at lower temperatures due to higher volatility, is about the same as Gasoline [12].

2.7 LPG and Ethanol blended as an alternative fuel in SI engines

The gaseous nature of the fuel/air mixture in an LPG vehicle's combustion chambers eliminates the cold-start problems associated with liquid fuels. LPG defuses in air fuel mixing at lower inlet temperature than is possible with either gasoline or diesel. This leads to easier starting, more reliable idling, smoother acceleration and more complete and efficient burning with less unburned hydrocarbons present in the exhaust. In contrast to gasoline engines, which produce high emission levels while running cold, LPG engine emissions remain similar whether the engine is cold or hot.

Also, because LPG enters an engine's combustion chambers as a vapor, it does not strip oil from cylinder walls or dilute the oil when the engine is cold.

This helps to have a longer service life and reduced maintenance costs of engine. Also helping in this regard is the fuel's high hydrogen to carbon ratio (C_3H_8), which enables propane powered vehicles to have less carbon build up than gasoline and diesel powered vehicles. LPG delivers roughly the same power, acceleration, and cruising speed characteristics as gasoline. Its high octane rating means engine's power output and fuel efficiency can be increased beyond what would be possible with a gasoline engine without causing Destructive Knocking. Such fine tuning can help compensate for the fuel's lower energy density. The higher ignition temperature of gas compared with petroleum based fuel leads to reduced auto ignition delay, less hazardous than any other petroleum based fuel and expected to produce less CO, NO_x emissions and may cause less ozone formation than gasoline and diesel engines

Properties of any fuel depend fully on its chemical compositions which determine the performance and emission characteristics of the engine. Ethanol is an oxygen enriched chemical agent; containing 35% oxygen by weight. It therefore can be treated as partially oxidized fuel [9].

When ethanol is added to the blended fuel (gasoline) it can provide more oxygen for the combustion process and leads to the so called leaning effect. Owing to the leaning effect engine combustion is improved. Lower heating value (LHV) has an average value of 26.8 MJ/Kg and the stoichiometric air to fuel ratio has a typical value of 9.0. In comparison with commercial gasoline, ethanol has higher density and octane number. In addition the high flash point (more than 56°C) of ethanol makes the storage and transportation issues less important. Ethanol has higher octane number than gasoline, thus it can lead in operation at higher compression ratios therefore, improvement in power output, efficiency and fuel consumption [4].

2.8 Safety precautions

2.8.1 Related to LPG

LPG is similar to other liquid fuels in some of its hazards. Additional hazards result from the pressure and properties of LPG.

Fire Hazards

LPG at ambient conditions is heavier than air and will descend from the location of a leak. Trained personnel must be aware of the ways to detect an LPG leak. Like natural gas, a small LPG leak may be detectable only by the smell of the odorant or by a combustible gas detector. Larger leaks may also be detected by their sound or by the appearance of frost.

As all fuels, smoking is prohibited when fueling LPG vehicles or working on their fuel systems. Safe work practices and facility design can eliminate potential ignition sources where LPG is handled or where leaked gas may accumulate (e.g., at floor level, in pits, and in trenches). As with natural gas, any LPG leak is considered a fire hazard, since a flammable concentration exists at the interface between a gas plume and the surrounding air.

Specific firefighting practices apply to LPG. Properly used halon and CO_2 fire extinguishers can effectively starve a small LPG fire for oxygen, and thus extinguish it. Some LPG vehicles in demonstration projects are equipped with automatic fire suppression systems. These systems are desirable because LPG is more flammable than diesel [8].

Pressure

The storage pressure of LPG poses certain hazards that are minimized by proper equipment and training. A pressurized fitting, if loosened while under pressure, could become a missile. Skin contact with a pressure-fed gas jet could result in a gas embolism in the bloodstream. More likely is a freeze burn caused by the drop in temperature at the point of a leak. Training that covers these hazards enables personnel to avoid them [8].

Other Hazards

Ingestion of LPG is unlikely because of the fuel's tendency to vaporize at ambient conditions. Asphyxiation is possible in a closed environment due to displacement of oxygen. Absorption through the skin is not considered a problem [8].

2.8.2 Related to ethanol blended fuel

Ethanol differs from Gasoline and diesel in its fire hazards. Like methanol, Gasoline, and diesel, ethanol is also toxic on ingestion.

Fire hazards

Because of ethanol's higher vapor pressure, ethanol spills are more likely to ignite than diesel spills. Ethanol burns with a slightly luminous flame, however the flames are virtually invisible in open sunlight. As other fuels, smoking should be prohibited when fueling ethanol vehicles and during any maintenance activities. The combustion properties of ethanol result in flammability limits that differ from those of gasoline. Ethanol does not ignite as readily as gasoline and it burns with a less intense flame. The flammability hazard of ethanol in vehicle fuel tanks is also different. In a Gasoline fuel tank, the vapor concentration is so high that the vapors are too rich to burn at temperatures above -20 °F (-7 °C). In a diesel fuel tank there are not enough vapors to support combustion under most conditions. The vapor space in a tank of 100 percent ethanol forms an ignitable mixture in the temperature range from 40 to 115°F (4 to 46°C).The risk of accidentally igniting these vapors is mitigated by installing flame arrestors on the fuel tank filler neck and vent. Potential ignition sources are eliminated from the inside of a tank by the design of the fuel system [1].

Fuel Toxicity

Ethanol can cause serious toxic effects from ingesting quantities as small as 100 milliliters. Extensive skin exposure can cause redness and irritation. Inhalation of high vapor concentrations can be toxic, however, inhalation of small quantities is not considered to be toxic. The American Council of Governmental Industrial Hygienists (ACGIH) exposure limit for ethanol vapor is 1,000 ppm. Appropriate safety training is similar to that for methanol, and includes information and safety practices that enable personnel to guard against ethanol exposure [8].

Hazardous Materials

Ethanol is a hazardous material because of its properties as a fuel. Personnel who handle hazardous materials receive training in spill cleanup and proper disposal of waste materials such as used fuel filters and oil filters [8].

2.9 Cost associated with running on LPG

There are three main types of cost that consumes would consider in switching to LPG. The three types of cost are [1].

- Capital cost
- Maintenance cost; and
- Fuel cost.

2.9.1 Capital cost

In switching to LPG, car owners can purchase LPG vehicles produced by car manufacturers commonly called original equipment manufacturers (OEMs) or convert their petrol-driven or diesel-driven vehicles in to using LPG.

Conversions in more common in the Netherlands, the US, Australia and Canada while dedicated LPG –driven vehicles produced by OEMs are more common in Japan. The cost of conversion varies from territories partly due to the availability of government subsidies on conversions in some territories.

But the capital cost is not needed to convert Gasoline- driven vehicle in to using Gasoline-ethanol blend fuel because it does not need any modification on the petrol engine [1].

2.9.2 Maintenance cost

LPG-driven vehicles have a slightly lower maintenance cost than petrol driven or diesel driven vehicles. LPG as a gas does not wash lubricant from the cylinder walls of the engine as gasoline and diesel. This washing action is detrimental to any component that really on the lubrication system for their proper functioning. The clear burning characteristics of LPG also reduce maintenance requirement and cost.

While Gasoline-ethanol blend vehicles requires no special maintenance. Due to their cleaner burning could lead to savings in maintenance costs through longer engine life and a reduction in the number of tune- ups [1].

2.9.3 Fuel cost

The switch to LPG and ethanol blended fuel involves a certain amount of initial cost but the running cost of LPG and ethanol blended –driven vehicles can be much lower than vehicles driven by petrol or diesel in money territories depending on government policy, especially that on fuel tax [1].

2.10 Limitations of LPG and Ethanol blend as a fuel in SI engine

The drawbacks of LPG and ethanol blended fuel include:

- In cold conditions, below 32 degrees Fahrenheit, starting could be a problem because of the low vapor pressure of LPG at low temperatures.
- LPG is generally higher priced than other fuel alternatives such as CNG and gasoline.
- Also, LPG is not safe to be used in vehicles running or plying on rough terrains and mountain roads.
- An LPG run car is less powerful than the car which uses diesel or petrol, since LPG is known to have low energy density.
- The relatively low boiling points and high vapor pressures of methyl and ethyl alcohol indicate that vapor lock could be a serious problem, particularly at high altitudes on warm summer days.
- The relatively high latent heats of methyl and ethyl alcohol cause problems in mixing these alcohols with air and transporting them through the intake manifold of the engine. Heating the intake manifold may be necessary in cold weather or before the engine reaches operating temperatures. Note that its latent heat is almost the same as the latent heat of octane.
- Less engine power is produced as the water content of an alcohol increases. Further, vapor lock, fuel mixing, and starting problems increase with water [4].

2.11 The future for LPG and Gasoline- ethanol blend as a fuel for SI engines

As environmentally friendly solutions become more popular with motorists and car manufacturers try to come up with greener models and concepts, LPG fuel is getting more and more exposure across the world- especially in models that are run as bi-fuel, using a tank of LPG and a tank of either petrol or diesel fuel –with the ability to switch between them when appropriate. Recent figures suggest that there are over 10 million LPG vehicles being used worldwide [3].

Bottlenecks, which could cause the development and deployment of LPG technologies to slow down, include the lack of appropriate infrastructure for fuel distribution and re-fuelling higher vehicle cost, and competition from other fuel options (e.g. bio/fuels) .

A steady supply of LPG at stable price is important in encouraging consumers to switch the fuel abundant local availability is a major factor to adopt LPG as an alternative fuel for vehicles. For example, the availability of LPG from Bass Strait was a key factor leading to rapid increase in utilization of LPG as a fuel for vehicles in 1970s in Australia [5].

While Ethanol blended fuel, has an interesting history and an intriguing future. At one point, proponents believed ethanol would provide the path to energy independence from Middle Eastern oil. Fast forward many years and this once promising idea has yet to pan out in the way that its early supporters envisioned. New technologies, however, have arisen since then, so investors should not give up on this potentially high-growth area.

Although ethanol has not replaced petroleum as the primary fuel source in the world, it has a widespread reach nonetheless. In the United States, most gasoline blends contain 10% ethanol. This E10 fuel came into popularity thanks to The Clean Air Act Amendments of 1990.

Due to the low percentage of ethanol, E10 is not considered an alternative fuel. Even so, the sheer volume of domestic gasoline consumption has easily made the United States the top producer of ethanol. Companies such as Archer Daniels Midland (ADM), Valero (VLO), and Green Plains (GPRE) account for a substantial portion of this production [8].

There are several factors that will continue to drive the growth of the ethanol blended fuel industry for the next decade, because of:

- Phase out of Methyl *tert*- butyl ether **(**MTBE)
- Ethanol price relative to crude oil (or gasoline)
- Clean octane
- Oxygenate for Reformulated Gasoline (RFG) program
- Gasoline extender (refinery capacity)
- Local economic development

CHAPTER THREE
MATERIALS AND METHODS

3.1 Research Design

The study was conducted at the mechanical and vehicle engineering workshop of Adama science and Technology University. A series of experiment were made on a vehicle equipped with a four cylinder, inline, naturally aspirated, Spark ignition engine.

The experiment involved the following tasks

- Gathering data as to the tractive effort, Power and fuel consumption produced by the test engine running on Gasoline- ethanol blend fuel under different vehicle speeds.
- Gathering data as to the tractive effort, Power and fuel consumption produced by the test engine running on LPG under different vehicle speeds.
- Gathering data as to the emission produced by the test engine running on Gasoline-ethanol blend fuel under different engine speeds.
- Gathering data as to the emission produced by the test engine running on LPG under different engine speeds.

After that the data like the tractive effort, Power, fuel consumption and the engine speed will be compiled. Then Microsoft excel is used to graph the data and compare the results for the two different test fuels.

3.2 Materials

3.2.1 Test vehicle and engine specification

Table 6: Research vehicle specification [1].

Research vehicle specification		
Make		Toyota
Model		KE20(corolla)
Transmission	Speed	4 speed
	Gear shift	Manual
	Gearbox model	K40

Figure 7: Toyota corolla KE20 Test vehicle

Table 7: Test engine specification [1].

<table>
<tr><td colspan="4">Test engine specification</td></tr>
<tr><td colspan="3">Engine model</td><td>3K</td></tr>
<tr><td colspan="3">Number of cylinder</td><td>4</td></tr>
<tr><td colspan="3">Bore and stroke</td><td>75x66</td></tr>
<tr><td colspan="3">Piston displacement</td><td>1166</td></tr>
<tr><td colspan="3">Compression ratio</td><td>9.0 :1</td></tr>
<tr><td rowspan="4">Valve timing</td><td rowspan="2">Intake</td><td>Opens (BTDC)</td><td>16^0</td></tr>
<tr><td>Closes(ATDC)</td><td>50^0</td></tr>
<tr><td rowspan="2">Exhaust</td><td>Open(BBDC)</td><td>50^0</td></tr>
<tr><td>Closes(ATDC)</td><td>16^0</td></tr>
<tr><td colspan="2" rowspan="4">Valve clearance</td><td rowspan="2">Intake valve (mm)</td><td>Cold: 0.13</td></tr>
<tr><td>Hot : 0.20</td></tr>
<tr><td rowspan="2">Exhaust valve(mm)</td><td>Cold: 0.23</td></tr>
<tr><td>Hot: 0.30</td></tr>
<tr><td colspan="3">Firing order</td><td>1-3-4-2</td></tr>
<tr><td colspan="3">Ignition timing(BTDC rpm)</td><td>8^0/ 600</td></tr>
<tr><td colspan="3">Cooling system</td><td>Liquid cooled</td></tr>
<tr><td colspan="3">Valve arrangement</td><td>Overhead valve</td></tr>
<tr><td colspan="3">Lubrication system</td><td>Forced-feed</td></tr>
<tr><td colspan="3">Intake charging</td><td>Naturally Aspirated</td></tr>
</table>

3.2.2 Test equipment

The experimental setup consists of a chassis dynamometer, an exhaust gas analyzer, tachometer a digital balance and volume flow meter for measuring the fuel consumption.

Table 8: Test equipment used

Test equipment		
Dynamometer	Type	Chassis dynamometer
	Model	Sun road-a-Matic XII
Emission analyzer		Crtpton 247 CO/HC emission analyzer
Tachometer		Veglia Boreletti Raylon Fissore
Digital balance		Eagle of PRC
Volume flow meter		Super ZHE ZHI

3.3 Methodology

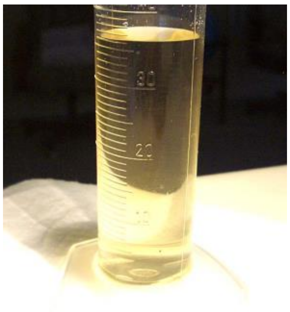
It is mostly experimental based and includes the following stages. The procedure of each stage is given below,

3.3.1 Test fuels

We used the following fuels in the experiment:

Pure Gasoline

Ethanol



10% Ethanol & 90% Gasoline

LPG

Figure 8: Fuel for test

3.3.2 Preparing test fuel blends

Blending Gasoline with Ethanol at a given percentage
The procedure we follow to blend the fuel is as follows:

I. Collecting apparatus needed to blend the fuel
II. Cleaning the apparatus used to blend the fuels
III. Blending 10% Ethanol with 90% of Gasoline in the graduated cylinder
IV. Stir while blending until it becomes homogeneous.

3.3.3 Modify the fuel system of Gasoline vehicle to use LPG

The following are the modifications done to the fuel system

- Install LPG storage tank and modify cylinder outlet valve,
- Install Pressure regulator/ vaporizer,
- Install Electronic cut-off valve on LPG regulator,
- Install Mixer (supply ring) and manufacture mixer mounting adapter on the carburetor air horn

3.4 Experimental procedure

3.4.1 Data Acquisition

Two sets of engine experiments were performed to evaluate the performance. The experiments were conducted for 90% Gasoline- 10% ethanol blend and LPG fuel. In all settings, the experiments were conducted as per the steps given below,

Step 1: Fuel blends were prepared by volume. The appropriate amount of ethanol was taken and then added to the Gasoline (applied for the ethanol blends only).

Step 2: The engine fuel tank was cleaned and filled with the fuel to be tested.

Step 3: The engine was run with the test fuel for about three minutes to get warm up and stabilize.

Step 4: The tractive force, power and fuel consumption at the rear wheel were recorded.

3.4.2 Measurement of tractive effort and power

The vehicle was driven on the chassis dynamometer and the tractive effort and wheel power is measured at each test speed. The test speed is with a 5km/hr intervals starting from 25km/hr, 25km/hr is the minimum speed with which a test can be done on the Sun Road – a-Matic XII classis dynamometer.

Figure 9. The sun road- a-matic XII chassis dynamometer

3.4.3 Measurement of fuel consumption

3.4.3.1 Gasoline-ethanol blend

Measurement of Gasoline- ethanol blend mass flow rate ($\dot{m}_f$) was made by recording a time taken to consume 10 grams of Gasoline- ethanol blend. A stop watch was used to note the time required to consume 10 grams of liquid Gasoline- ethanol blend at wide open throttle of the speed under consideration. For example if the test vehicle is being driven at 25 km/hr, the operator will keep the engine running at the maximum load by fully depressing the accelerator pedal while an assistant takes note of the time taken to consume the indicated amount of Gasoline- ethanol blend. And this result helps in calculating the specific fuel consumption at each speed.

Figure 10: Measuring fuel consumption of Gasoline- ethanol blend

3.4.3.2 LPG

Measurement of LPG fuel consumption was made by recording a time taken to consume $0.001m^3$ of LPG. A stop watch was used to capture the required to consume the mentioned volume of LPG at wide open throttle of the speed under consideration. For example if the test vehicle is being driven at 25km/hr, the operator will keep the engine running at the maximum load by the fully depressing the accelerator pedal while an assistant takes note of the time taken to consume the indicated of gas. Specific fuel consumption at each speed can then be calculated based on the values obtained.

3.4.4 Measurement of exhaust emission

The main objective of exhaust emission test was first to measure the engine emission in Gasoline- ethanol blended mode and LPG mode and next to compare the results obtained. The exhaust gas emission was measured using CO/HC emission analyzer at 5000 rpm interval starting from 1000 rpm. First the Gasoline- ethanol blend emission was measured by using the original fuel system. Next the emission of the newly introduced LPG fuel was done.

3.4.5 Gasoline- ethanol blend fuel system

The purpose of the Gasoline-Ethanol blend fuel system is to store, transfer, and filter and supply the Gasoline-Ethanol blend fuel required by the float chamber of a carburetor. The most important components of the system are shown on figure 11:

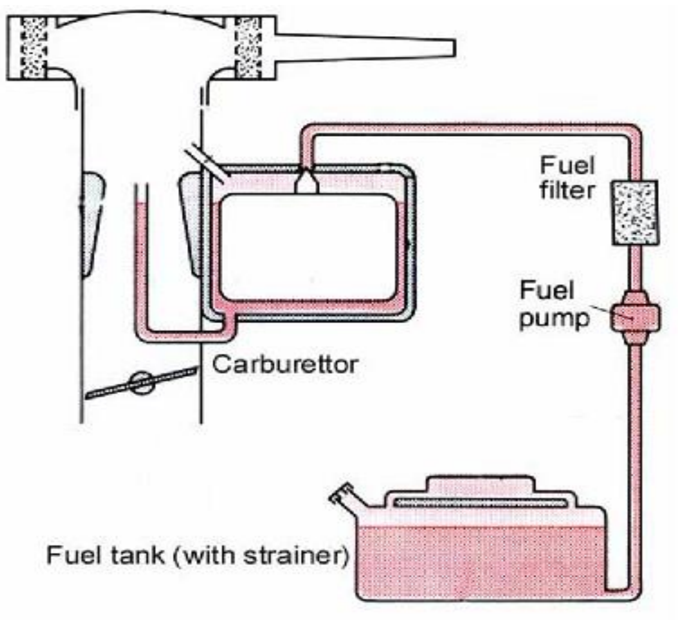


Figure 11: Gasoline-Ethanol blend fuel system

3.4.6 LPG fuel system

Vehicles converted to use LPG can be bi-fuel vehicles have two separate fuel system, with only one fuel being used at a time [3]. Many LPG vehicles are converted Gasoline vehicles so the LPG which is existing in liquid state in cylinder is to be converted to gaseous state. This means LPG has enters the cylinder inlet manifold in the form of a gas or vapour before being burnt in the cylinder.

The convention kits include a regulator/vaporizer that changes liquid LPG to a gaseous form and an air /fuel mixer that meters and mixes the fuel with filtered intake air before the mixture is drawn into the engine's combustion chambers [9][8]. The experimental LPG fuel system is shown on figure 12.

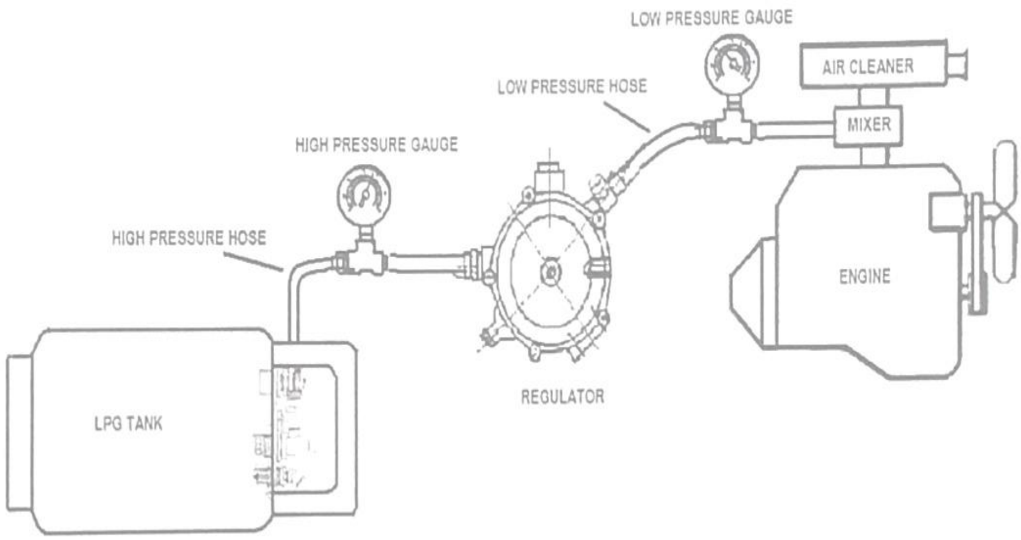


Figure 12: Experimental LPG fuel system.

3.4.7 Components and basic understanding of the LPG system

3.4.7.1 LPG storage tank

LPG vehicle require a special fuel tank that is strong enough to withstand the LPG storage pressure of about 8.96 bars [8]. As vehicle LPG tanks are not currently available on the market, a cooking stove LPG cylinder shown on figure 13 is used for the research.

Figure 13: LPG storage tank (cylinder)

The domestic LPG cylinders are fitted with a valve regulator that will allow only a limited gas supply. The gas output from the tank’s valve regulator was found to be below the operating pressure of the LPG fuel system. To eliminate this problem and make sure adequate supply of LPG, the LPG tank valve regulator has been modified and a mechanical opening mechanism has been developed. The locally modified valve opening mechanism is shown in Figure 14.

(a) before modification (b) after modification

Figure 14: Modified LPG cylinder outlet valve

The LPG fuel tank can be secured directly to the underside of the rear luggage compartment floor as indicated on figure15.

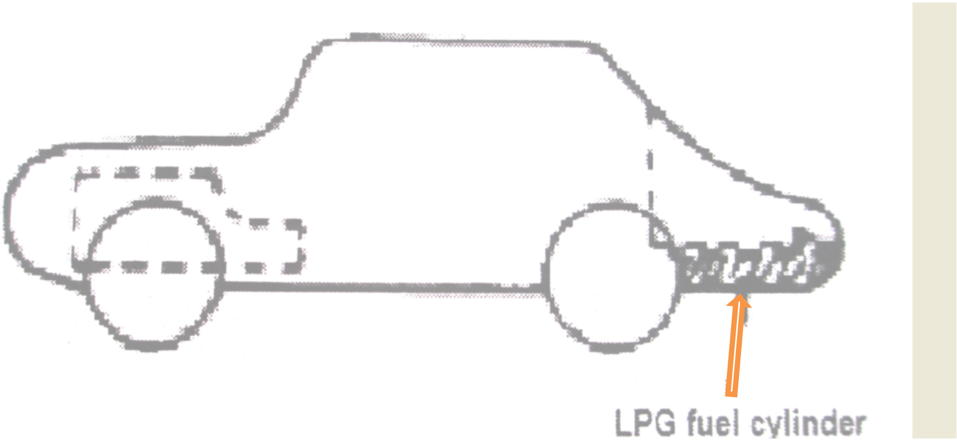


Figure 15: Location of LPG fuel cylinder

As shown on Figure 16 the LPG tank and the Gasoline-ethanol blend fuel tank can co-exist at the rear of the vehicle reducing the risk of fuel spillage in case of head accidents.

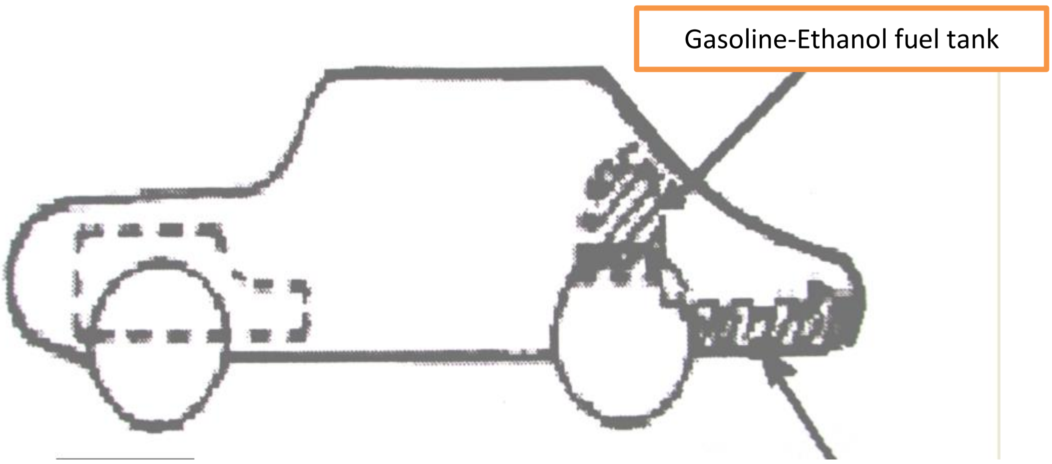


Figure 16: Location of Gasoline-ethanol blend and LPG fuel tank

3.4.7.2 Regulator/vaporizer

The regulator is used to vaporize the liquid gas and regulate the amount of LPG that goes to the engine. LPG used in motor cars is stored on board the vehicle in a steel cylinder in liquid form, but is converted to gaseous form via a regulator before supply to a gas-air mixer (the equivalent of a carburetor) for intake to the engine [12].

When the vehicle starts using LPG, some of the pressure in the LPG tank is released. Some of the liquid LPG then boils to produce vapor. Heat is needed to convert the liquid to vapor (known as the latent heat of vaporization). As the liquid boils, it draws the heat energy from its surrounding. When the vehicle stops using LPG, the pressure will return to the equilibrium value for the surrounding temperature. The pressure of the LPG in the container varies with the surrounding temperature. It is also much higher than is needed by the appliance that uses it; it needs to be controlled to ensure a supply at constant pressure. This is done by a regulator, which limits the pressure to suit the appliance that is being fuelled; in this case the engine.

For the research under consideration, LANDI RENZO version 'ECO4' pressure regulator has been used. 'ECO4' pressure regulators are designed for the conversion to LPG of vehicle with catalytic converter and engine with fuel injection system or carburetor. Figure 17 shows 'ECO4' pressure regulator.

'ECO4' LPG regulator is a device that reduces the LPG pressure and vaporizes the gas, allowing regular flow of gas as the engine requires. It is fitted with two LPG pressure reduction stages that provide stability when supplying both large and small amount of gas. The passage of the LPG from the liquid to the gaseous phase occurs by pressure drop and absorption of heat from the pressure regulator elements heated by the fluid in the engine cooling circuit. The flow of gas needed for the engine to idle is activated by a dedicated solenoid valve, and supplied through the main flow gas pipe. Fitted with an electronic device incorporating a safety system that internals to close the gas solenoid valve when the engine is turned off, including accidentally.

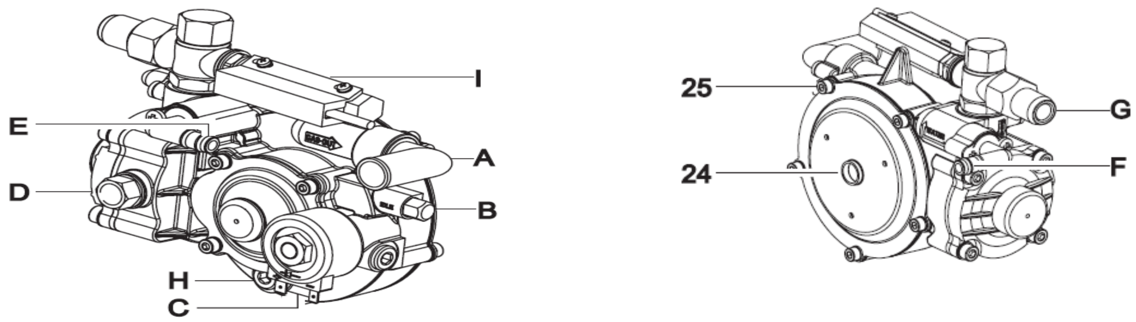


Figure 17: ‘ECO4’ pressure regulator

Legend

A) Gas outlet
B) Throttle adjustment screw.
C) Solenoid valve positive and negative contact.
D) Safety valve.
E) Water outlet connector to attach to an enginewater circuit outlet pipe.
F) Water inlet connector to attach to a return pipeof the engine water circuit.
G) Gas Inlet.
H) Bleed tap.
I) Pressure sensor.

The regulator is connected to the LPG cylinder and the engine by using rubber hoses to ensure flexibility that allows for engine movement and prevent vibration from being transmitted to body.

3.4.7.3 Electronic cut off valve

The purpose of the electronic cut off valve is to shut off supply of LPG to engine when it is stopped or when the vehicle is not in use thus preventing gas seepage over time. The default position of the electronic cut-off valve is “closed “unless powered up. The ‘ECO4’ pressure regulator has a solenoid valve that intermarries to close the passage inside the LPG regulator when the engine is turned off, including accidentally.

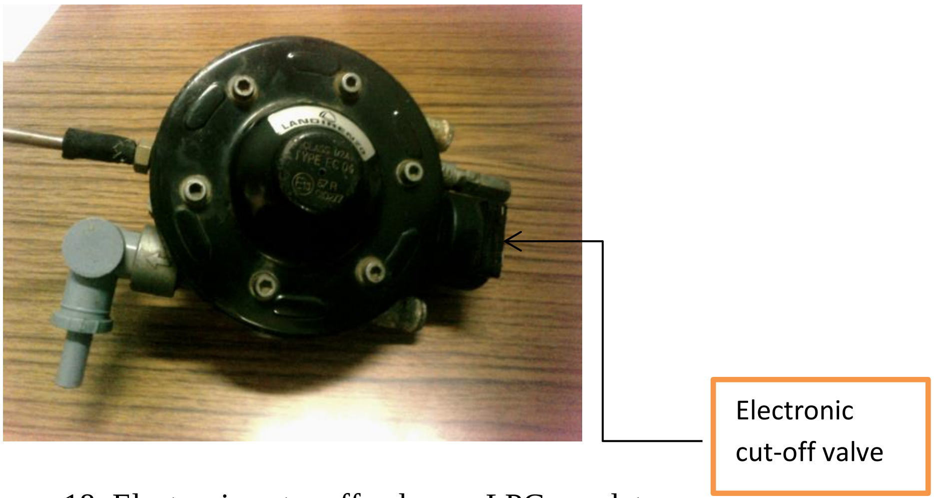


Figure 18: Electronic cut – off valve on LPG regulator

3.4.7.4 Mixer (supply ring) with adapter

The mixer is a flow passage of decreasing cross section which reaches a minimum at the throat. It is used to mix the LPG fuel with air before it enters the engine. The air passing through the mixer during suction stroke increasing in velocity and the pressure in the mixer throat decreases. The decrease in pressure at the throat of the mixer creates a depression in the LPG regulator allowing proportional gas to pass through and mix with the incoming airstream. As shown on Figure 19 the mixer has been mounted above the carburetor.

Figure 19: Mixer

3.4.7.5 Main flow adjuster

To adjust LPG system to the engine a throttle valve that is found in the carburetor is used. It is a round disc or butterfly valve that allows continuous control of the rate at which air- fuel mixture enters the engine’s intake manifold.

Same throttle valve is being used in the research engine for the Gasoline/ Gasoline- ethanol blend and LPG fuel control the throttle valve is located between the carburetor venture and the engine inlet of the induction system. It directly regulates the amount of air entering the engine, indirectly controlling the fuel burned in each cycle.

As shown in the figure the throttle valve is mechanically linked to and controlled with a throttle pedal. Depressing the accelerator pedal opens the throttle valve and permits an increased amount of air fuel mixture to reach the engine cylinders. This will increase the power output and speed of the engine.

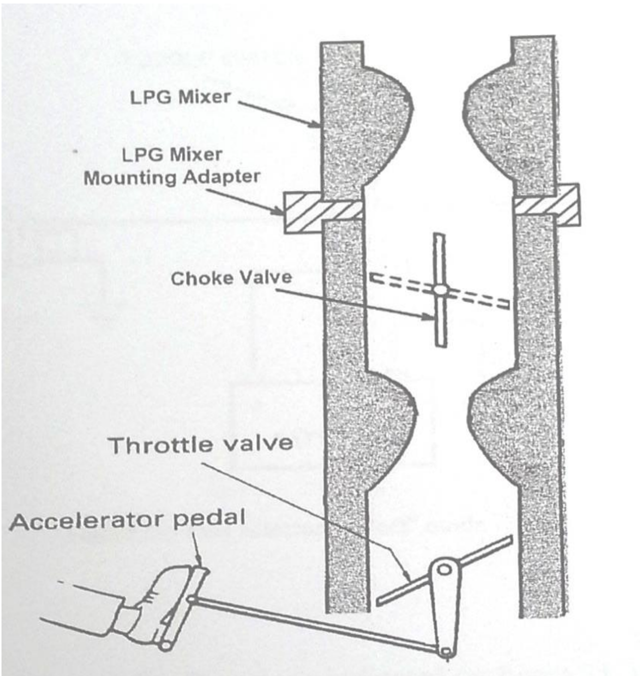


Figure 20: LPG and Gasoline-ethanol blend supply control

3.4.7.6 Fuel selector switch

To allow switching between LPG and gasoline-ethanol blend a switch has been provided. The fuel selector (toggle switch) is made to control operation of an electric fuel pump and LPG regulator solenoid one at a time.

The test vehicle was originally fitted with a mechanical fuel pump. A mechanical fuel pump will supply fuel to the engine as long as the engine is running, and this provides no room for gasoline-ethanol blend shut off to the engine. To provide room for gasoline-ethanol blend shutoff and introduce LPG to the system, the electrical fuel pump allows gasoline-ethanol blend supply only when gasoline fuel system is selected. Fuel selector switch (toggle switch) has been installed inside the cabin to allow the driver select the fuel to be used.

When the fuel selector is on the “off” mode as indicated on Figure 21 no fuel is supplied to the engine. This allows total fuel shutoff when the engine is stopped or when some maintenance on the engine without the need for fuel system operation.

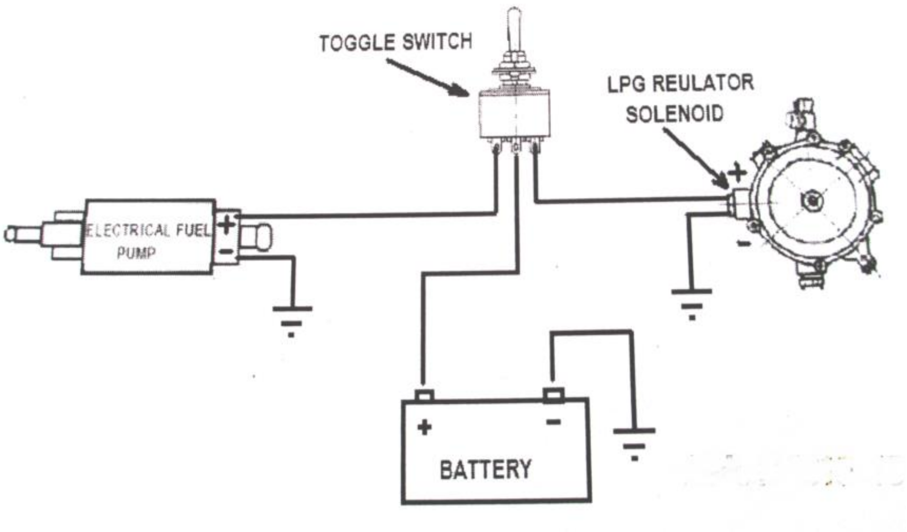


Figure 21: Fuel selector on off mode

When the fuel selector is on the Gasoline-ethanol blend mode as indicated on figure 22, the electric fuel pump will be supplied with battery voltage allowing Gasoline-ethanol blend supply to the engine.

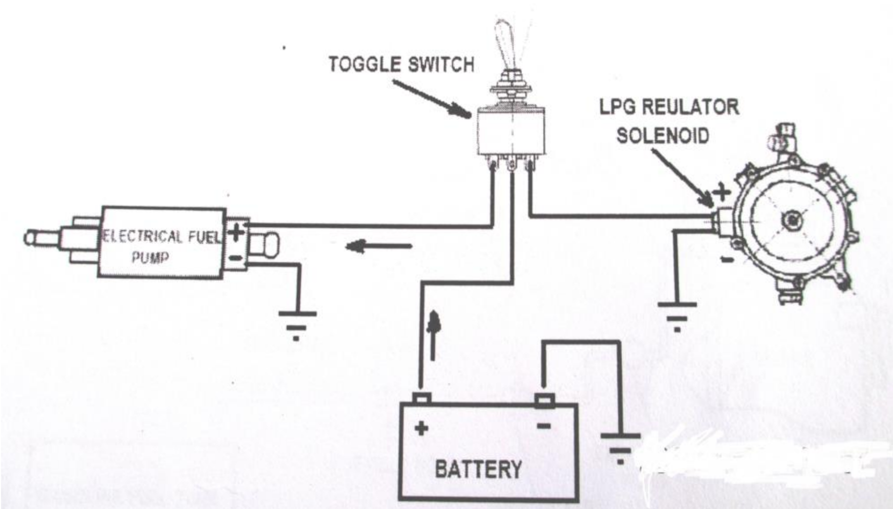


Fig 22: Fuel selector on Gasoline- ethanol blend mode

When the fuel selector is on the “LPG” mode as indicated on the Figure 23, the LPG regulator solenoid will be supplied with battery voltage allowing supply of LPG to the engine.

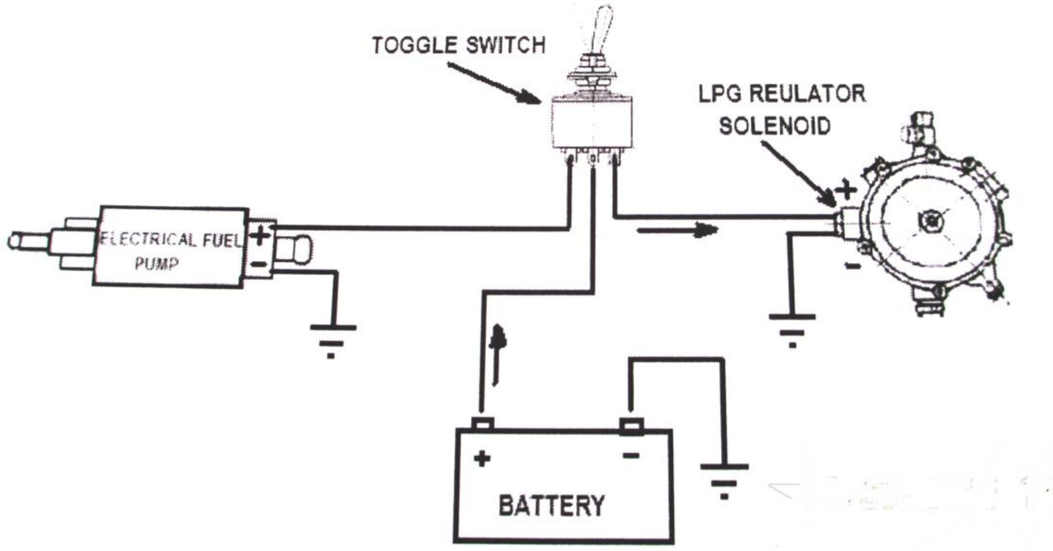


Figure 23: Fuel selector on “LPG” mode

3.4.7.7 Fuel indicator

Lamp indicator is used to give a displayed indication of the fuel system in use. When the vehicle is running on gasoline-ethanol blend, an indicator light on the dashboard will illuminate, another indicator light will illuminate when the vehicle is being driven on LPG. The final fuel system, with options to run either on gasoline-ethanol blend or on LPG is displayed on Figure 24.

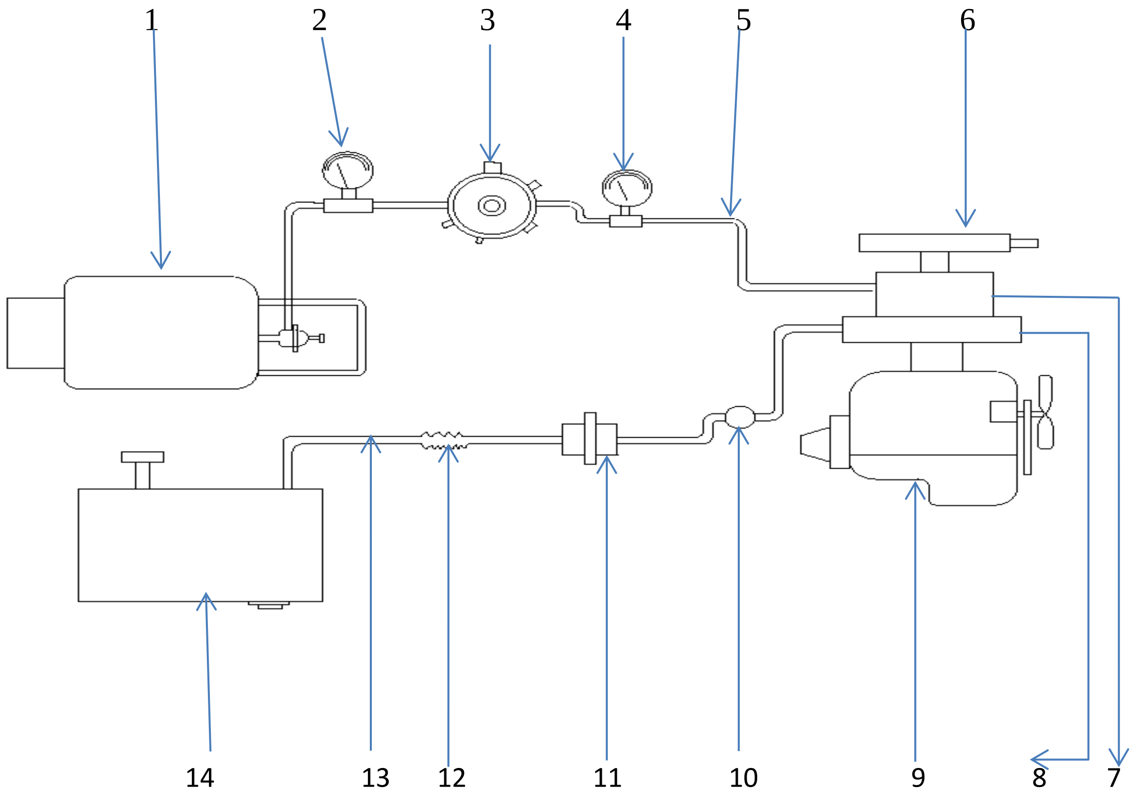


Figure 24: The fuel system run either on Gasoline-Ethanol blend or on LPG

Legend:-

1) LPG fuel tank
2) High pressure gauge
3) Regulator
4) Low pressure gauge
5) Low pressure hose
6) Air cleaner
7) Mixer
8) Carburetor
9) Engine
10) Electrical fuel pump
11) Fuel filter
12) Flexible hose
13) Fuel lline
14) Ethanol-Gasoline blend fuel tank

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Evaluation of combustion emission

Combustion may be defined as a relatively rapid chemical combination of hydrogen and carbon in the fuel with the oxygen in the air resulting in liberation of energy in the form of heat. The combustion process is a fast exothermic gas- phase reaction.

Complete combustion means that all carbon is converted to CO_2; all hydrogen is converted to H_2O. Complete combustion is nearly impossible to achieve. In practice, the exhaust gas of an internal combustion engine contains incomplete combustion products such as CO, H_2, unburned hydrocarbons, soot as well as complete combustion products such as CO_2 and H_2O.

Under lean operating conditions the amounts of incomplete combustion products are small. Under fuel- rich operating conditions these amounts become more substantial since there is insufficient oxygen to complete combustion [4].

If sufficient oxygen is available, a hydrocarbon fuel can be completely oxidized. The carbon in the fuel is then converted to carbon dioxide (CO_2) and the hydrogen to water (H_2O). For example, consider the overall chemical equation for the complete combustion of one mole of propane C_3H_8:

$$C_3H_8 + aO_2 \rightarrow bCO_2 + cH_2O \quad \text{...} (1)$$

A carbon balance between the reactants and products gives b = 3. A hydrogen balance gives 2c = 8, or c = 4. An oxygen balance gives 2b + c = 10 = $2a$, or $a = 5$. Thus the reaction becomes:

$$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O \quad \text{...} (2)$$

Note that equation (2) only relates the elemental composition of the reactant and product species; it does not indicate the process by which combustion proceeds, which is much more complex.

Generally, the chemical equation for stoichiometric burning of hydrocarbon in oxygen is [1].

$$C_aH_b + (a + \frac{b}{4})\, O_2 \rightarrow aCO_2 + \frac{b}{2} H_2O \quad \text{...} (3)$$

Air contains nitrogen, but when the products are at low temperatures the nitrogen is not significantly affected by the reaction. Consider the complete combustion of a general hydrocarbon fuel of average molecular composition C_aH_b with air. The overall complete combustion equation is:

$$C_aH_b + (a + \frac{b}{4})\,(O_2 + 3.773N2) \rightarrow aCO_2 + \frac{b}{2}\,H_2O + 3.773\,(a + \frac{b}{4})\,N_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

For example, the burning of propane is:

$$C_3H_8 + 5O_2 + 18.8N_2 \rightarrow 3CO_2 + 4H_2O + 18.8N_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

In practice, complete combustion is nearly impossible to achieve as many factors affect the combustion in a spark ignition engine. The exhaust gas therefore contains incomplete combustion products. Generally, the chemical equation for stoichiometric incomplete combustion of hydrocarbon in oxygen is as follows:

$$(z)\ C_aH_y + (z\,(\frac{a}{2} + \frac{b}{4}))\ O_2 \rightarrow z \cdot a\ CO + (\frac{z.b}{2})\ H_2O \quad \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

For example, the incomplete combustion of propane is:

$$2C_3H_8 + 7O_2 \rightarrow 2C + 2CO + 8H_2O + 2CO_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

As it can be seen from equation (7) exhaust gases of the incomplete combustion contain carbon monoxide which is regarded as a pollutant. If excess hydrocarbon is used in the combustion or if there is no enough time or no enough oxygen for complete combustion, unburned hydrocarbons will also join the outgoing exhaust [1].

4.1.1 Carbon monoxide (CO) Emission

CO is generated in an engine when it is operated with a fuel- rich equivalence ratio. When there is not enough oxygen to convert all carbon to CO_2, some fuel does not get burned and some carbon ends up as CO. Typically the exhaust of an SI engine will be about 0.2% to 5% carbon monoxide. Not only is CO considered undesirable emission, but it also represents lost chemical energy that was not fully utilized in the engine [4]. Table 9 shows the CO emission test result obtained from the test vehicle by using exhaust gas analyzer which indicated below on figure 25.

Figure 25 Measuring CO emission by using exhaust gas analyzer

Table 9: CO Emission values

Engine speed (rpm)	CO% (Gasoline- Ethanol blend)	CO% (LPG)
1000	0.8	1.80
1500	1	1.60
2000	1.8	1.40
2500	2.5	2.00
3000	3	n/a
3500	3.4	n/a

The %CO versus engine speed graph will be as follows:

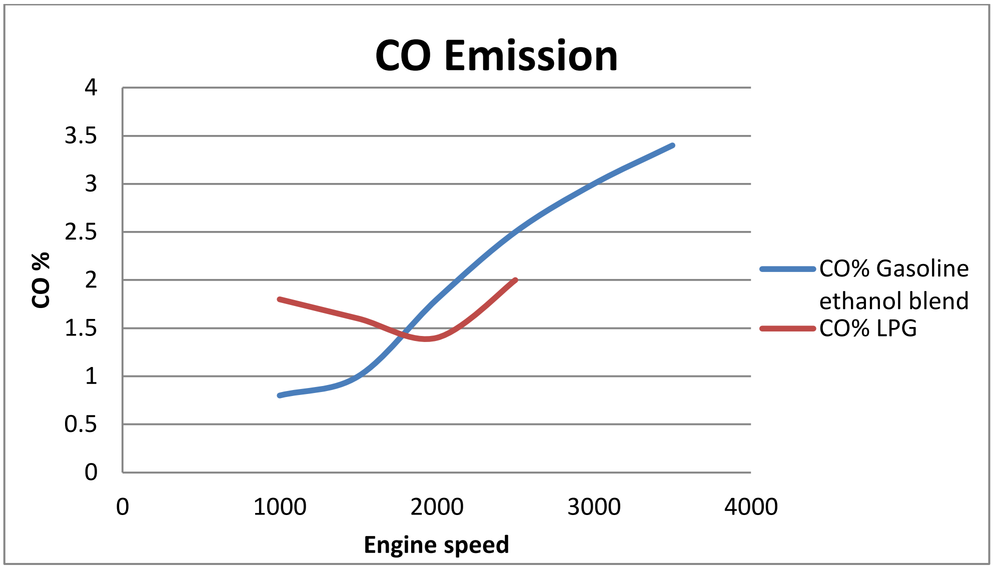


Figure 26: CO Emission curve

4.1.1.1 Gasoline- Ethanol blend CO Emission

As it can be seen from the graph on figure 26, Gasoline- Ethanol blend carbon monoxide emission decreased slightly at low engine speeds but increased at higher engine speeds. This is because at lower engine speeds, there is relatively enough time for combustion, i.e; at lower speeds the time elapsed during combustion is slightly higher, and hence there is a relatively higher possibility for the conversion of carbon to CO_2.

Maximum CO is generated when an engine runs rich, such as when accelerating under load. This is evident from the nature of the curve; as the engine rpm increases with full load application the CO Emission raises. As the engine speed increases under wide open throttle, the carburetor power circuit starts supplying additional fuel to the incoming air. This makes the air fuel mixture to become richer. When the engine is run with this rich mixture there is not enough oxygen to convert all carbon to $CO_2$and hence CO Emission increases.

The other reason for the rise of CO Emission at high speed is the fact that there is relatively lesser charge filling. As the engine speed increases, the duration for intake valve opening decreases and hence intake valve closes before the cylinder is entirely filled with air consequently there is a deficiency of oxygen to react with all the carbon in the fuel.

Even when the intake air/fuel mixture is stoichiometric or lean, some CO will be generated in the engine. Poor mixing, local rich regions, and incomplete combustion will create some CO.

4.1.1.2 LPG CO Emission

The CO emission graph on figure 26 shows that LPG carbon monoxide Emission is slightly higher at low engine speeds then drops to 1.4% at around 2000 rpm and starts rising again at higher engine speeds. It appears that at 2000 rpm good charge mixing and better combustion is happening resulting in reduced CO Emission.

At low engine rpm, swirl decreases; air- fuel mixing will be less rapid. Incomplete mixing of the air and fuel results in some fuel particles not finding oxygen to react with. This increases CO Emissions.

Carbon monoxide (CO) Emissions from internal combustion engines are controlled primarily by the air- fuel equivalence ratio. Spark- ignition engines often operate close to stoichiometric at part load and fuel rich at full load. For fuel- rich mixtures the amount of excess fuel increases and hence; CO concentrations in the exhaust increases.

With a fuel- rich mixture there is not enough oxygen to react with all the carbon, resulting in high levels of CO in the exhaust products. This is particularly true at low engine speeds when the air- fuel mixture is purposely made very rich.

At low speed, the heavier than air LPG will have sufficient time to displace the incoming air and consequently the air- fuel ratio will become richer increasing CO Emission. At higher speed, short opening duration of the intake valve leads to oxygen scarcity, consequently some fuel particles fail to find oxygen to react with leading to increased CO Emission.

4.1.1.3 Comparison of Gasoline- Ethanol blend and LPG CO Emission

As far as CO Emission is concerned, LPG is proved to be cleaner than Gasoline- Ethanol blend. This is basically because in comparison to Gasoline- Ethanol blend, LPG has a low carbon to hydrogen ratio, which means that it generates lower amounts of carbon monoxide. In addition because of its gaseous nature, LPG mixes with air more readily than Gasoline- ethanol blend leading to more fuel particles finding oxygen to react with.

4.1.2 Hydrocarbon (HC) Emission

Exhaust gases leaving the combustion chamber of an SI engine contain unburned fuel components and partially reacted components. This partially reacted particles consist of small molecules which are formed when large fuel molecules break up (thermal cracking) during the combustion reaction. It is often convenient to treat these molecules as if they contained one carbon atom, as HC [4].

Hydrocarbons are basically a product of incomplete combustion of fuel. If rich fuel mixture is used there is not enough oxygen to react with all the carbon, resulting in high levels of HC in the exhaust products. Often as an engine ages clearance between the pistons and cylinder walls increases due to wear. This increases oil consumption and contributes to an increase in HC Emissions [4]. Table 10 shows the HC emission test result obtained from the test vehicle by using exhaust gas analyzer which indicated below on figure 27.

Figure 27: Measuring HC Emission by using exhaust gas analyzer

Table 10: HC Emission test results

Engine speed (rpm)	HC (ppm) (Gasoline- Ethanol blend)	HC (ppm) (LPG)
1000	2150	2400
1500	2100	2200
2000	2000	2200
2500	1800	1550
3000	2000	2000
3500	2250	n/a

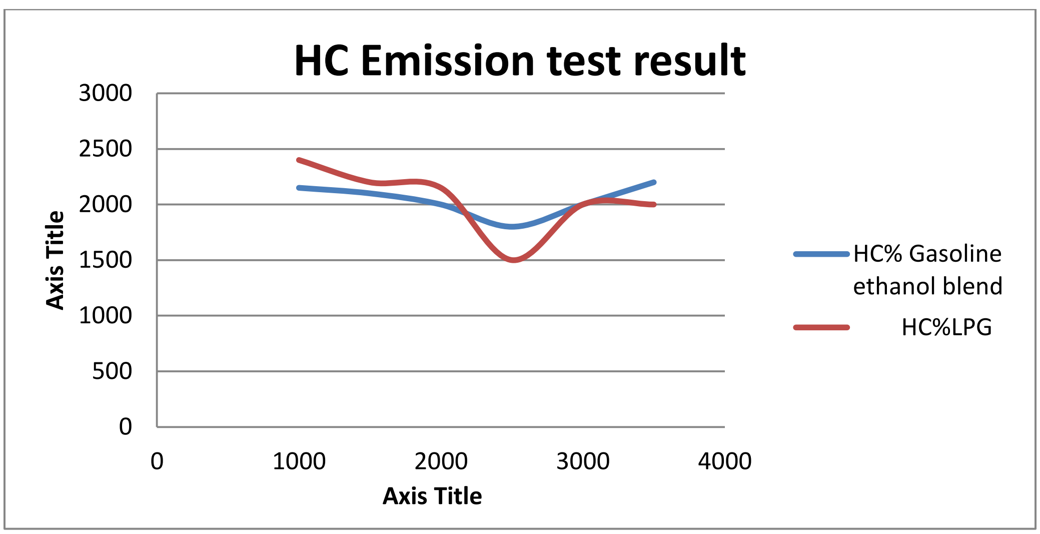


Figure 28: HC Emission curves

At low engine speed, both Gasoline- Ethanol blend and LPG HC Emissions are higher. For example at 1000 rpm, LPG registered 2400 ppm of HC whereas Gasoline- Ethanol blend registered 2150. These values are high compared to the HC values registered at 2500 rpm. The HC values start to rise again past 2500 rpm.

At low engine speeds and at wide open throttle under load, the air- fuel ratio is intentionally made rich. A fuel rich air- fuel ratio does not have enough oxygen to react with all the carbon and hydrogen, and therefore; HC Emission increases.

At low engine speed, incomplete mixing of the air and fuel results in some fuel particles not finding oxygen to react with. This incomplete combustion results in a rise of HC Emission.

During valve overlap, both the exhaust and intake valves are open, creating a path where air- fuel intake can flow directly in to the exhaust. A well- designed engine minimizes this flow, but a small amount can occur. The worst condition for this is at idle and low speed, when real time of overlap is greatest. This will increase HC Emission at low engine speed.

If very lean mixture is used poorer combustion occurs, resulting in HC Emissions. The extreme of poor combustion for a cycle is total misfire. This occurs more often as air- fuel ratio is made leaner.

4.1.2.1 Comparison of Gasoline- Ethanol blend and LPG HC Emission

At lower engine speeds, LPG HC Emission is found to be greater than that of gasoline- Ethanol blend. This could be regarded to the gaseous nature LPG which makes it more susceptible to leaking past the exhaust valve during valve overlap and even after valve overlap.

Compared to LPG, Gasoline- Ethanol blend has exhibited little variation over the emission test cycle. More instability on the part of the LPG could be due to its gaseous nature which makes its density largely variable as engine speed and temperature changes. Variation in the density of LPG in turn will result in variation of displaced incoming air mass, making the air- fuel ratio to be fluctuating. This leads to varied HC.

LPG has registered the least HC Emission of 1550 ppm at 2500 rpm. This has to do with its composition. LPG contains only short chain hydrocarbons which can be thermally cracked at more ease than Gasoline- Ethanol blend which contains relatively complex chain hydrocarbons.

The Emission results obtained can shortly be summarized as follows:

- Except at very low engine speeds, the carbon monoxide Emission of LPG is found to be less than that of Gasoline- Ethanol blend. Especially the CO Emission of LPG in the vicinity of 2000 rpm show that LPG combustion is clean than Gasoline- Ethanol blend combustion. CO Emissions of both fuels tend to increase at high speed.

- CO emission variation over the operating range is small for LPG as compared to that of Gasoline- ethanol blend. The Gasoline- Ethanol blend CO Emission has varied from 1% CO up to 3.6% CO, whereas, LPG CO Emission varied only from 1.8% CO to 2% CO. this shows that LPG has a somewhat more stable CO Emission when compared to Gasoline- Ethanol blend.
- The least HC Emission is attained when running on LPG. LPG HC Emission at 2500 rpm is found to be the least HC Emission of all the test speeds.

4.2 Evaluation of Torque

There are two basic types of dynamometers, the engine dynamo and the rolling road or chassis dynamometer. The rolling road is very convenient as it requires only driving a car on to a set of rollers and run the engine to find the power and torque output.

Sun Road- a- Matic XII chassis dynamometer has been used for the current research. The chassis dynamometer is capable of measuring the power output and the tractive effort applied at the drive wheels. The power actually available at the engine crankshaft, called the brake power, can be computed if the transmission losses and drive train gear ratios are known.

The tractive effort recorded at the drive wheels can later be used to determine the torque produced by the engine. A relation for converting the tractive effort at the wheels to torque can be used once the radius of the drive wheels is known.

4.2.1 Tractive effort

The force available at the contact between the rear wheel tires and road is known as tractive effort. Tractive effort (F) obtained from the chassis dynamometer test is presented on table 11.

Table 11: Gasoline- Ethanol blend and LPG tactive effort data

Vehicle speed (Km/hr)	Tractive effort (kN) Gasoline- Ethanol blend			
	1st gear	2nd gear	3rd gear	4th gear
25	2.7	1.75	1.15	0.70
30	2.55	1.8	1.20	0.75
35	2	1.8	1.19	0.75
40		1.70	1.15	0.80
45		1.55	1.05	0.85
50		1.40	1.10	0.82
55		1.30	1.05	0.80
60		1.15	1.05	0.80
65		1.10	1.00	0.75
70		0.9	0.90	0.75
75		0.2	0.8	0.70
80			0.8	0.70
85			0.75	0.70
90			0.50	0.65
95				0.65
100				0.55

Vehicle speed (Km/hr)	Tractive effort (kN) (LPG)			
	1st gear	2nd gear	3rd gear	4th gear
25		1.50	1.05	0.60
30		1.45	1.10	0.70
35		0.90	1.05	0.70
40			0.90	0.75
45			0.80	0.65
50			0.55	0.55
55			0.30	0.40
60			0.20	0.35

When the vehicle is driven with first gear, the engine is running at its maximum speed. When the vehicle is driven by 25 km/hr of first gear, the engine rpm is 3999.99 rpm. At 30 km/hr, rpm reaches 4799.15 km/hr, and at 35 km/hr engine runs at 5599 rpm.

At high engine rpm charge filling is adversely affected due to very short intake stroke duration. The fact that gaseous LPG is supplied to the engine will make the situation even worse because LPG will displace the incoming air. Consequently, when the engine is running at first gear no tractive effort and no wheel power is registered by the chassis dynamometer. The charge is not sufficient enough to produce a power that is capable of producing a tractive force that can be sensed by the chassis dynamometer.

In addition, at high engine speeds, friction power is increased significantly. The rise of friction power reduces the power that will be available at the drive wheels; as a result, no significant tractive effort is registered. The heat loss through the exhaust also increases as the speed increase, thus reducing tractive effort.

The tractive effort at different gears has a behavior of increasing for a while and then drops. This is basically due to reduction in charge filling as engine speed increases. Once the tractive effort start dropping, the values of tractive effort are insignificant to the research and therefore the values of tractive effort after some vehicle speed are intentionally omitted. Same trend is to be used throughout the research.

4.2.2 Wheel Torque

Having known the tractive effort and the drive wheel radius, the drive wheel torque can be calculated from:

$$F = \frac{T_w}{r} \qquad \text{...} \quad (8)$$

Where F = tractive effort

T_w = torque at rear wheels

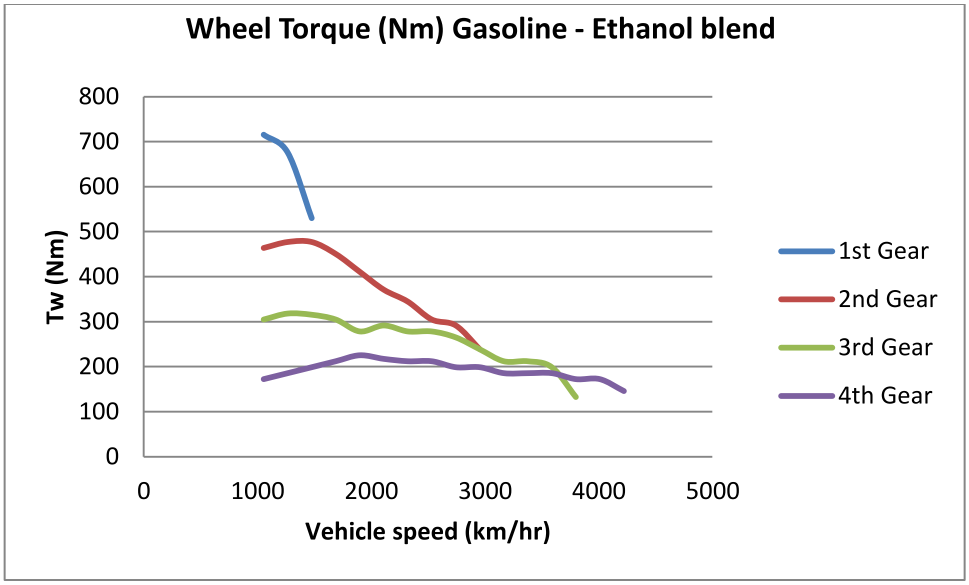
r = radius of tire in meter

The radius of the rear tire is measured to be 0.265 meters. Inserting the obtained radius in the above equation and computing for torque at the rear wheels gives the results presented on table (12)

Table 12: Wheel Torque values

Vehicle speed (Km/hr)	Wheel Torque (Nm) Gasoline-Ethanol blend			
	1st gear	2nd gear	3rd gear	4th gear
25	715.5	463.75	304.75	172.25
30	675.75	477	318	185.5
35	530	477	315.35	198.75
40		450.5	304.75	212
45		410.75	278.25	225.25
50		371	291.5	217.3
55		344.5	278.25	212
60		304.75	278.25	212
65		291.5	265	198.75
70		238.5	238.5	198.75
75			212	185.5
80			212	185.5
85			198.75	185.5
90			132.5	172.25
95				172.25
100				145.75

Vehicle speed (Km/hr)	Wheel Torque (Nm) (LPG)			
	1st gear	2nd gear	3rd gear	4th gear
25		397.5	278.25	172.25
30		384.25	291.5	185.5
35		238.5	278.25	185.5
40			238.5	198.75
45			212	172.25
50			145.75	145.75
55			79.5	119.25
60			53	92.75



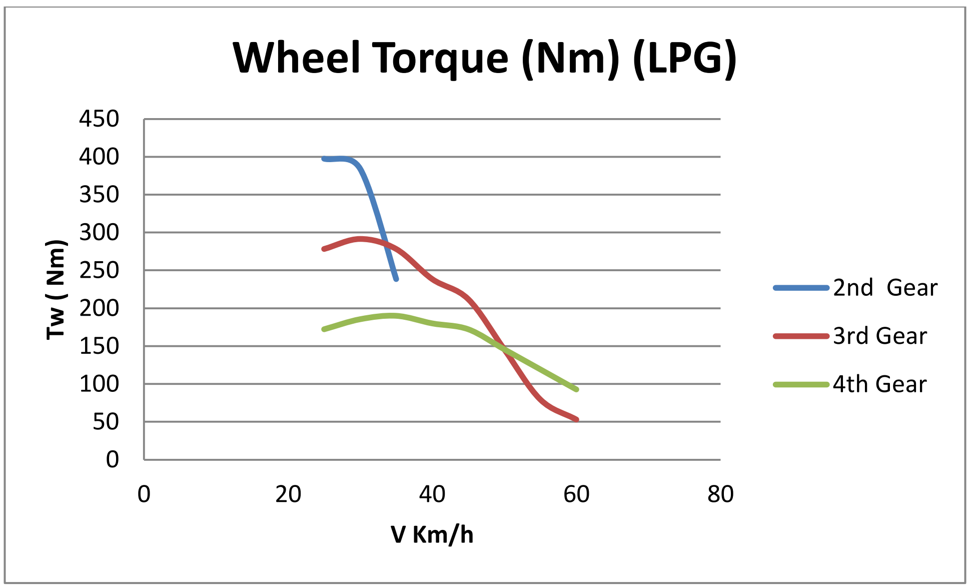


Figure 29: Wheel torque graphs for Gasoline- ethanol blend and LPG

4.2.3 Brake torque (T_b)

Once the torque at the wheels is known, the brake toque can be calculated by using the following relation:

$$T_w = (\text{g. r x } a\text{.r})\ \eta_t .\ T_b \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Where T_w = torque at rear wheels

g.r = gearbox gear ratio

$a.$ r = back axle ratio

η_t = overall transmission efficiency

T_b = brake torque

The test vehicle (Toyota corolla model KE20) uses manual gearbox type K40. This is a 4 speed transmission with the following gear ratios:

Table 13: KE20 gear ratios

Gear	1^{st}	2^{nd}	3^{rd}	4^{th}
Gear ratio	3.789	2.220	1.435	1
Back axle ratio				4.222

For torque at the tire surface transmission efficiency of 0.90 at top gear and 0.80 at other gears can be assumed.

Now from equation (9) we can find the value of engine torque (T_b) in kgf.m to be:

$$T_b = \frac{T_w}{(\text{g.r x a.r})\ \eta_t} \quad \text{……………………………………………………} \ (10)$$

Table 14 shows the engine torque at each test speed using Gasoline- ethanol blend and LPG fuels one at a time.

Table 14: Gasoline- Ethanol blend and LPG brake torque values

Vehicle speed (Km/hr)	Brake Torque (Nm) Gasoline- Ethanol blend							
	1st gear	N	2nd gear	N	3rd gear	N	4th gear	N
25	55.94	3999.29	61.83	2343.21	62.83	1514.64	48.99	1055.5
30	52.83	4799.15	63.6	2811.85	65.57	1817.57	52.49	1266.6
35	41.44	5599.01	63.6	3280.49	65.02	2120.5	52.57	1477.7
40			60.06	3749.14	62.84	2423.43	56.08	1688.8
45			54.77	4217.78	57.37	2726.36	59.59	1899.9
50			49.47	4686.42	60.1	3029.29	57.49	2111
55			45.93	5155.06	57.37	3332.21	56.08	2322.1
60			40.63	5623.7	57.37	3635.14	56.08	2533.2
65			38.87	6092.35	54.64	3938.07	52.58	2744.3
70			31.8	6560.99	49.17	4241	52.58	2955.4
75					43.71	4543.93	49.07	3166.5
80					43.71	4846.86	49.07	3377.6
85					40.98	5149.78	49.07	3588.7
90					27.31	5452.71	45.57	3799.8
95							45.57	4010.9
100							38.56	4222

Vehicle speed (Km/hr)	Brake Torque (Nm) (LPG)						
	1st gear	2nd gear	N	3rd gear	N	4th gear	N
25		53	2343.21	57.37	1514.643	45.57	1055.5
30		51.23	2811.85	60.1	1817.571	49.07	1266.6
35		31.8	3280.49	57.37	2120.5	49.07	1477.7
40				49.18	2423.428	52.58	1688.8
45				43.71	2726.357	45.57	1899.9
50				30.05	3029.285	38.56	2111
55				16.34	3332.214	31.55	2322.1
60				10.93	3635.142	24.54	2533.2

After finding the brake torque at different gears, the brake torque versus engine speed graph can be drawn.

The chassis dynamometer used for the test doesn't have engine revolution counter, it rather displays wheel speed in Km/hr. It is therefore necessary to calculate the engine speed (N) from the wheel speed.

Depending on the gear selected, there is speed reduction from the engine to drive wheels; consequently the engine speed for each gear has to be treated separately.

The relationship between engine revolution (N) and vehicle speed (V) depends on the overall gear ratio. The engine revolution and vehicle speed can be related with the following expression:

The driving speed is:

$$\frac{2\pi rN}{\text{g.r x a.r}} = \frac{1000V\ (\text{km/hr})}{60} \quad \ldots\ldots (11)$$

$$N = \frac{V \text{ x g.r x a.r x } 1000}{C_R \text{x } 60}\left(\frac{\text{rev}}{\text{min}}\right) \quad \ldots\ldots (12)$$

$$N = \frac{2.65xV \text{ x g.r x a.r}}{r}\left(\frac{\text{rev}}{\text{min}}\right) \quad \ldots\ldots (13)$$

Where: C_R = the driving wheel circumference in m = 2π x tire radius

N = the engine speed in rpm

g.r = gearbox gear ratio

a.r = back axle ratio

The radius of the test vehicle's rear tire is measured to be 0.265 m; the gear ratios of each speed and the axle gear ratio are as shown in table 12 and hence can be substituted in equation (13) to calculate N.

Once the values of engine speed are found, brake torque versus engine speed graph can be constructed. Figure 29 and 30 show the brake torque curves obtain

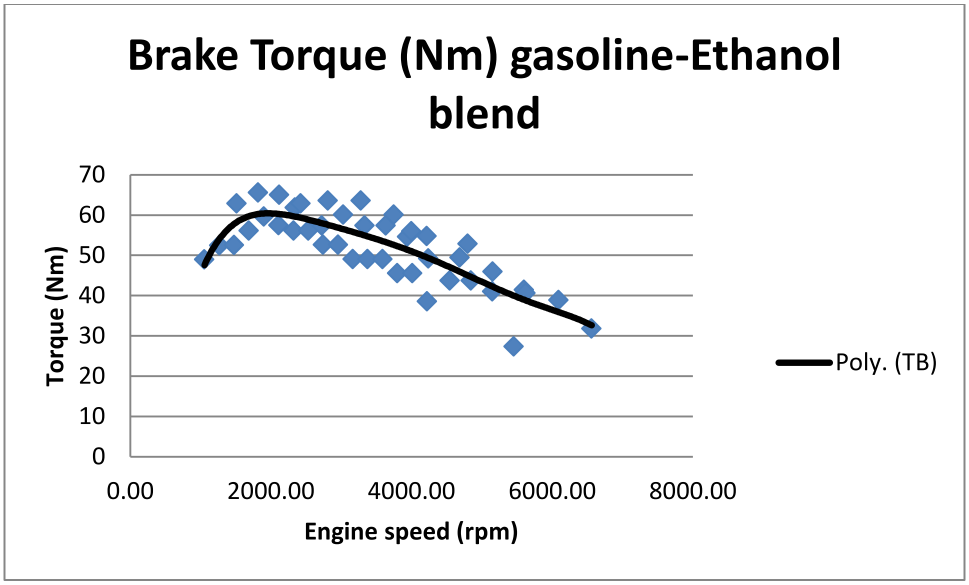


Figure 30: Gasoline- Ethanol blend brake torque curve

When running on Gasoline- Ethanol blend, a maximum brake torque of 65.57 Nm was found at 1817.57 rpm.

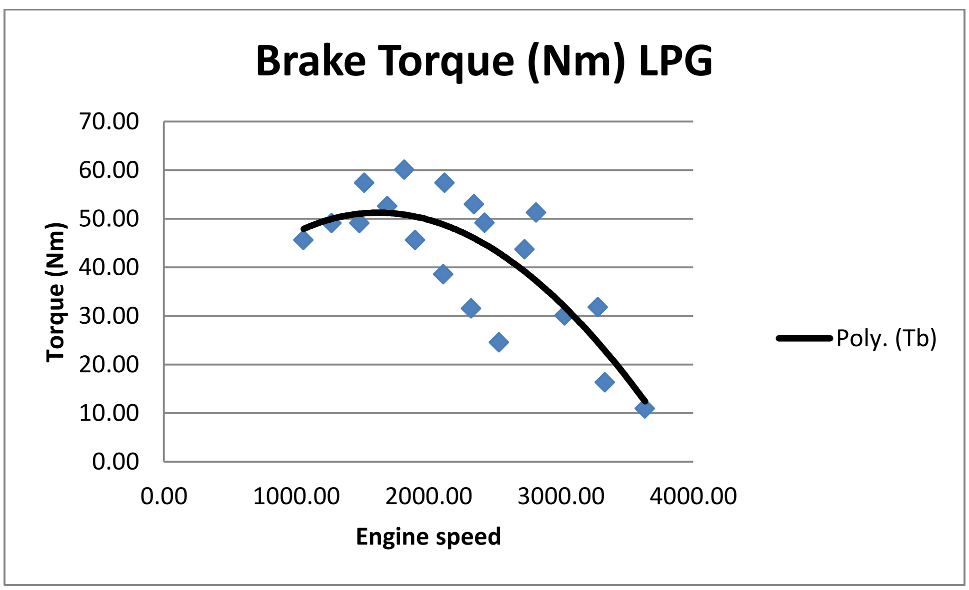


Figure 31: LPG brake torque curve

When running on LPG, the maximum brake torque of 60.10 Nm was found at 1817.57 rpm.

As can be seen from the graphs on figures 29 and 30, brake torque drops at low engine speed then rises for a while and drops again. The reason for brake torque's drops off at lower speeds is due to heat losses. The percentage heat rejected to coolant is more at lower speed. When engine is running at low speed, there is a relatively longer time for heat conduction to engine parts and then to the coolant; this will reduce the heat available for doing work. The percentage heat rejected to coolant is reduces at higher speeds. As engine speed increases there is a relatively shorter time for heat loss and torque reduction due to heat loss will be minimal, thus brake torque rises.

One reason for brake torque's drop off at higher speeds is because of reduction in charge filling, i.e.; it becomes more difficult to ingest a full charge of air in to the cylinders. As engine speed increases there is a relatively shorter opening duration for the intake valves, the valves close before the cylinder is fully filled with air- fuel mixture, consequently brake power starts to fall.

The other reason for brake torque reduction at higher speeds is because a considerably more heat is carried by exhaust at higher speeds. As the engine speed increases, the exhaust valves open sooner than they open at lower speed; this will carry away some of the combustion heat and consequently, torque drops as speed increases.

The brake torque results obtained can shortly be summarized as follows:

- Gasoline- Ethanol blend has produced more brake torque than LPG. When running on Gasoline- Ethanol blend a maximum brake torque of 65.57 Nm was found and when running on LPG a maximum brake torque of 60.10 Nm was found. The least brake torque of 10.93 Nm is also registered when running on LPG. The average torque when running on Gasoline- ethanol blend is 46.44 Nm and for LPG it is 35.52 Nm. On average LPG has shown 23.51% reduction in brake torque. The lesser energy density of LPG and the lesser cylinder filling (due to charge displacement) are responsible for LPG's reduced brake torque.
- As engine speed increases from medium to high, the LPG brake torque graph drops faster than the Gasoline- Ethanol blend curve. However; when the test vehicle is driven at 30 km/hr on 4th gear, LPG has registered 6.52% torque reduction than Gasoline- Ethanol blend. At 40 and 25 km/hr on 4th gear, LPG's brake torque reduction is 6.24% and 6.98% respectively. When the test vehicle is driven at 25 km/hr and 30 km/hr on 3rd gear, LPG's torque reduction is 8.69% and 8.34% respectively.

4.3 Evaluation of power

Brake power is the useful power output from the engine, available at the crankshaft. Brake power can be found in two methods using the data collected from the chassis dynamometer test. One method is converting wheel power to brake power by using transmission efficiency. Given the power at the wheels, the brake power can be calculated by dividing the power at the wheel by the product of all transmission efficiencies.

$$P_b = \frac{P_w}{\eta_t} \quad \text{...} \quad (14)$$

Where P_b = brake power

P_w = power at the wheels

η_t = overall transmission efficiency (gear efficiency x rear axle efficiency)

T_e = engine torque

Another method of finding the brake power is calculating engine power from the already found engine torque; brake power can be found from the engine torque using the following relation:

$$P_b = \frac{2\pi N T_b}{1000} \quad \text{...} \quad (15)$$

Where P_b = brake power in KW

N = engine speed in rev/ sec

T_b = brake torque N-m

Table 15 shows the values of P_b obtained by using equation (15).

Table 15: Brake power values

Vehicle speed (Km/hr)	Brake power (KW) Gasoline-ethanol blend			
	1st gear	2nd gear	3rd gear	4th gear
25	23.42	15.16	9.96	5.41
30	26.54	18.72	12.47	6.96
35	24.29	21.84	14.43	8.13
40		23.57	15.94	9.91
45		24.18	16.37	11.85
50		24.27	19.06	12.70
55		24.78	20.01	13.63
60		23.92	21.83	14.87
65		24.79	22.52	15.10
70		21.84	21.83	16.26
75			20.79	16.26
80			22.17	17.35
85			22.09	18.43
90			15.59	18.12
95				19.13
100				17.04

Vehicle speed (Km/hr)	Brake power (KW) (LPG)			
	1st gear	2nd gear	3rd gear	4th gear
25		13.0	9.1	5.03
30		15.1	11.4	6.51
35		10.9	12.7	7.59
40			12.5	9.29
45			12.5	9.06
50			9.5	8.52
55			5.7	7.67
60			4.2	6.51

Once the brake power at each gear is known, graph indicating the brake power versus engine speed can be constructed.

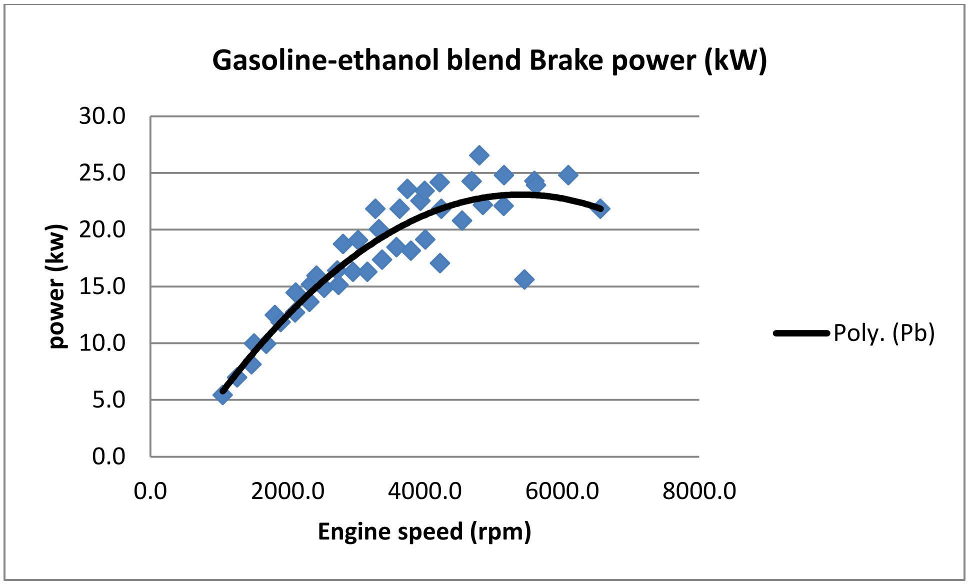


Figure 32: Gasoline- Ethanol blend brake power curve

A maximum brake power of 26.54 KW is obtained at 4799.15 rpm when running on Gasoline-Ethanol blend.

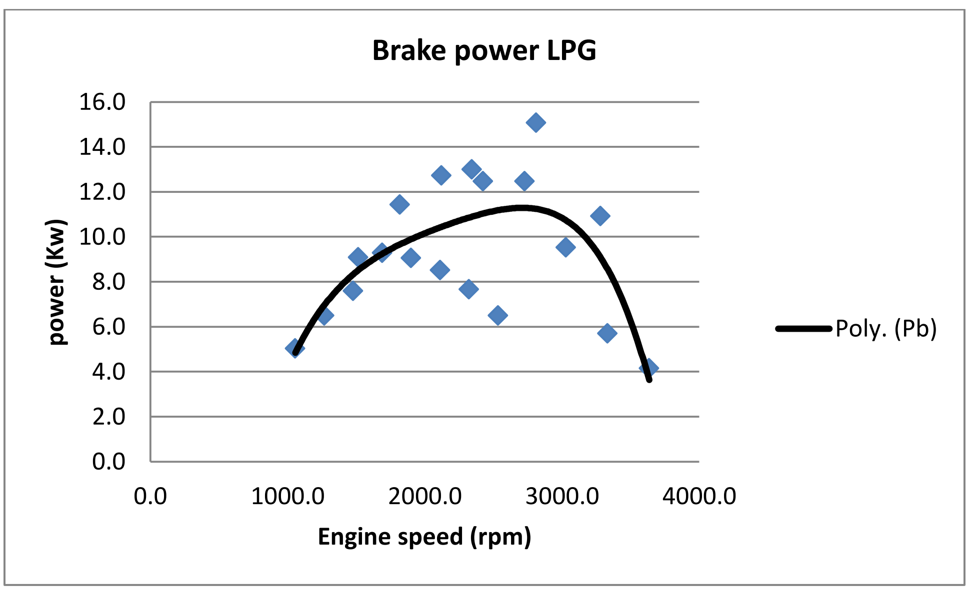


Figure 33 LPG brake power curve

A maximum brake power of 15.1 KW is obtained at 2811.85 rpm when running on LPG. At low engine speed the friction power is relatively low and therefore the brake power increases with speed. As engine speed increases, however, the friction power starts to increase at continuously greater rate and therefore P_b reaches a peak and starts reducing. At engine speeds above the usual operating range, friction power increases very rapidly.

Another reason for the falling off brake power at high speed is less complete filling of the cylinder consequent on greater reduction of pressure. The fact that valve timing is designed for moderately high speed will indirectly reduce the brake power at low speeds.

The brake power results obtained can shortly be summarized as follows:

- The average brake power for Gasoline- ethanol blend operation is 15.97 kW and for LPG it is 9.65 kW. When average values of brake power are compared, LPG shows a 39.57% reduction. Comparing their maximum brake power, LPG shows a reduction of 43.1%. However; at lower vehicle speeds the brake power reduction is comparatively small. For example, when the vehicle is driven at 30 km/hr on 4^{th} gear, the brake power reduction is only 6.46%. At 25 km/hr on 3^{rd} gear the reduction is 8.63%, at 30 km/hr of 3^{rd} gear reduction is 8.58%, at 35 on 3^{rd} gear reduction is 11.98%, at 25 km/hr on 4^{th} gear reduction is 7.02% and at 40 km/hr on 4^{th} gear reduction is 6.26%.

4.4 Evaluation of brake specific fuel consumption

In engine tests, the fuel consumption is measured as a flow rate; mass flow per unit time ($\dot{m}_f$). A more useful parameter is the specific fuel consumption (sfc) the fuel flow rate per unit power output. It measures how efficiently an engine is using the fuel supplied to produce work.

$$\text{Specific fuel consumption (sfc)} = \frac{\text{mass flow rate } (\dot{m}_f)}{\text{power (P)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (16)$$

$$\text{Brake specific fuel consumption } (bsfc) = \frac{\text{mass flow rate } (\dot{m}_f)}{\text{brake power (Pb)}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (17)$$

Measurement of Gasoline- Ethanol blend consumption was made by recording a time taken to consume 10 grams Gasoline- ethanol blend. The mass flow per unit time, $\dot{m}_f$ of Gasoline-Ethanol blend consumed is calculated by dividing 10 gm to the time taken for its consumption. The value thus obtained at each test speed and running gear is shown table 16.

Figure 34 Measurement of LPG Fuel consumption

Measurement of LPG fuel consumption was made by recording a time taken to consume $0.001m^3$of LPG. At atmospheric conditions of the test day $0.001m^3$ of LPG is equivalent to 0.52887 gm. And hence the volume flow rate can be converted to mass flow rate using this data and dividing it to the time taken for its consumption. Table 16 shows the mass flow rate of LPG.

Table 16: Mass flow rate of fuel

Vehicle speed (Km/hr)	Gasoline- Ethanol blend mass flow rate (gm/sec)			
	1st gear	2nd gear	3rd gear	4th gear
25	2.23	1.58	1.10	0.98
30	2.55	2.60	1.36	1.09
35	3.80	2.68	1.47	1.15
40		2.70	1.40	1.29
45		2.75	1.55	1.16
50		2.80	1.60	1.17
55		2.85	1.89	1.14
60		3.12	1.90	1.35
65		2.90	1.95	1.49
70		2.80	2.19	1.75
75			2.30	1.78
80			2.48	1.84
85			2.06	1.62
90			1.83	1.58
95				1.75
100				1.71

Vehicle speed (km/hr)	LPG mass flow rate (gm/sec)			
	1st gear	2nd gear	3rd gear	4th gear
25		0.32	0.29	0.14
30		0.28	0.23	0.15
35		0.31	0.24	0.19
40			0.17	0.20
45			0.32	0.35
50			0.20	0.35
55			0.35	0.33
60			0.31	0.33

Once the mass flow rate of the fuel is determined, the brake specific fuel consumption can be calculated using the formula given at (18) which is taken from (17).

$$(bsfc) = \frac{\dot{m}_f\left(\frac{gm}{sec}\right) x\ 3600}{Pb}\left(\frac{gm}{kwhr}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

Table 17: Brake specific fuel consumption values

Vehicle speed (Km/hr)	Gasoline- Ethanol blend bsfc (gm/kwhr)			
	1st gear	2nd gear	3rd gear	4th gear
25	356.8	392.27	415.09	665.66
30	365.73	510.08	377.19	577
35	669.07	463.84	383.4	481.39
40		422.60	354.19	464.4
45		439.80	356.77	397.7
50		409.75	311.19	334.2
55		429.28	328.53	309.73
60		467.22	333.82	355.26
65		446.15	327.12	357.36
70		553.84	348.69	388.64
75			393.9	390
80			360	405.89
85			384.84	338.28
90			446.34	323.36
95				347.7
100				376.7

Vehicle speed (km/hr)	LPG bsfc (gm/kwhr)			
	1st gear	2nd gear	3rd gear	4th gear
25		83.85	119.49	107.33
30		69.98	71.72	82.73
35		100.33	71.00	90.62
40			55.11	78.59
45			104.55	140.18
50			105.54	160.79
55			217.98	173.64
60			263.34	185.36

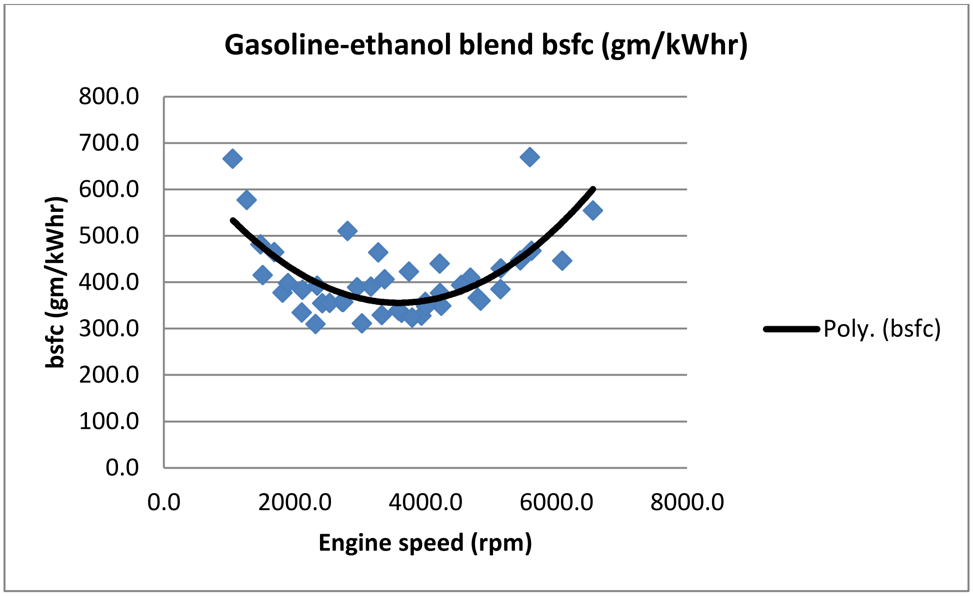


Figure 35: Gasoline- Ethanol blend bsfc curve

The least bsfc of 309.7 gm/kwhr is found at 2322.1 rpm when running on Gasoline- Ethanol blend

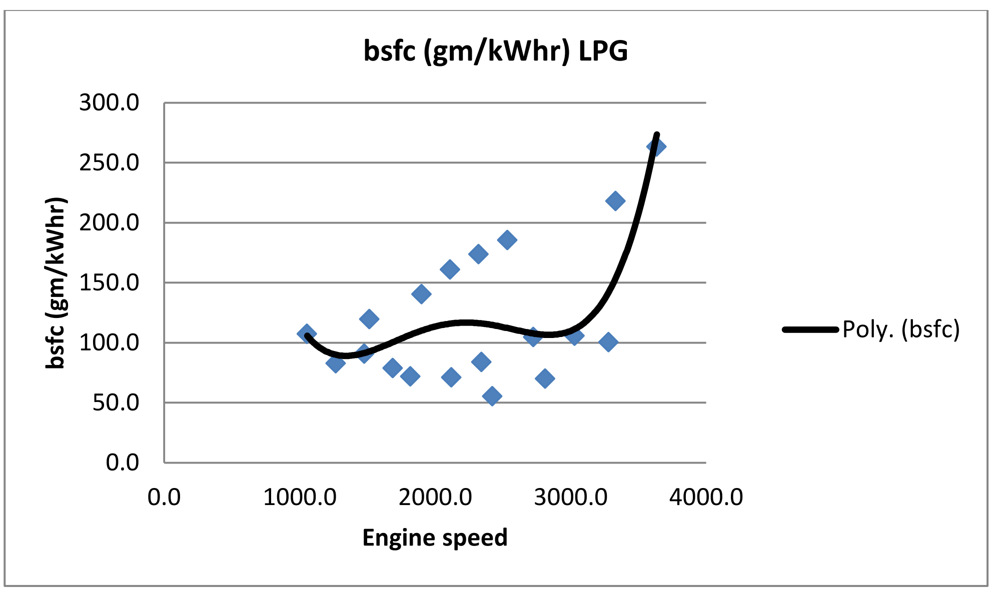


Figure 36: LPG bsfc curve

The least bsfc of 55.11 gm/kwhr is found at 2423.4 rpm when running on LPG.

At low engine speeds, fuel is intentionally made rich. When fuel is rich there exists much unused fuel in the exhaust; consequently, at low rpm engine consumes more fuel to produce power. This makes the bsfc to be large at low engine speed as shown on figure 35.

Minimum bsfc occurs at stoichiometric fuel ratio or with a slightly lean mixture when all the fuel burn. As can been seen from the graph on figure 35, this happens around 2322.1 rpm. After this rpm, bsfc starts to rise because the power circuit in the carburetor starts supplying additional fuel, making the air- fuel ratio richer again. Less time for fuel mixing and higher exhaust gas temperature increase bsfc at higher speeds.

From figure 34 it can be seen that even though bsfc of LPG is considerably low at low engine speed, it increases rather sharply at speeds in excess of 2200 rpm. This is congruent to the rise of HC emissions at high speed shown on figure 27.

At high engine speed, there is less time for air induction to the cylinders; in addition, the LPG gas will further displace some of the incoming air, making the mixture even richer than it already is. This not only increases HC emission but also increases bsfc because fuel consumption will suffer if there is unburned fuel somewhere in the cylinder.

The brake specific fuel consumption results obtained can shortly be summarized as follows:

- The brake specific fuel consumption (bsfc) results show that the performance of LPG is better than Gasoline- Ethanol blend. The least bsfc of 309.7 gm/kwhr is found at 2322.1 rpm when running on Gasoline- ethanol blend and the least bsfc of 55.11 gm/kwhr is found at 2423.4 rpm when running on LPG. When fuelled with LPG an average bsfc of 159.25 gm/kwhr is obtained, but on Gasoline- Ethanol blend the average bsfc was 489.4 gm/kwhr.

4.5 Brake thermal efficiency

The thermal efficiency of an engine is important since it determines how efficiently the fuel is being used in the engine. Using the data obtained as a brake power, the brake thermal efficiency can be calculated.

The brake thermal efficiency (η_{bt}) is the ratio of energy in the brake power to the fuel energy.

$$\eta_{bt} = \frac{P_b}{\dot{m}_f \times Q_{LHV}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (19)$$

Where P_b = brake power/sec

$\dot{m}_f$ = mass of fuel/sec (volume in case of gaseous fuel)

Q_{LHV} = lower calorific value of fuel in KJ/Kg

From literature the lower heating value of Gasoline- ethanol blend is 27 MJ/Kg. The LHV of vapor LPG is 47.7 MJ/Kg. using this values and calculating the brake thermal efficiency gives the curves shown at figures 36 and 37.

Table 18: Brake thermal efficiency values

Vehicle speed (Km/hr)	Brake thermal efficiency (Gasoline-Ethanol blend)			
	1st gear	2nd gear	3rd gear	4th gear
25	0.39	0.36	0.34	0.20
30	0.39	0.27	0.34	0.24
35	0.24	0.30	0.36	0.26
40		0.32	0.42	0.28
45		0.33	0.39	0.38
50		0.32	0.44	0.40
55		0.32	0.39	0.44
60		0.28	0.43	0.41
65		0.32	0.43	0.38
70		0.29	0.37	0.34
75			0.33	0.34
80			0.33	0.35
85			0.40	0.42
90			0.32	0.42
95				0.40
100				0.37

Vehicle speed (km/hr)	Brake thermal efficiency (LPG)			
	1st gear	2nd gear	3rd gear	4th gear
25		0.30	0.21	0.05
30		0.31	0.27	0.07
35		0.25	0.30	0.11
40			0.29	0.14
45			0.29	0.23
50			0.22	0.22
55			0.13	0.19
60			0.10	0.16

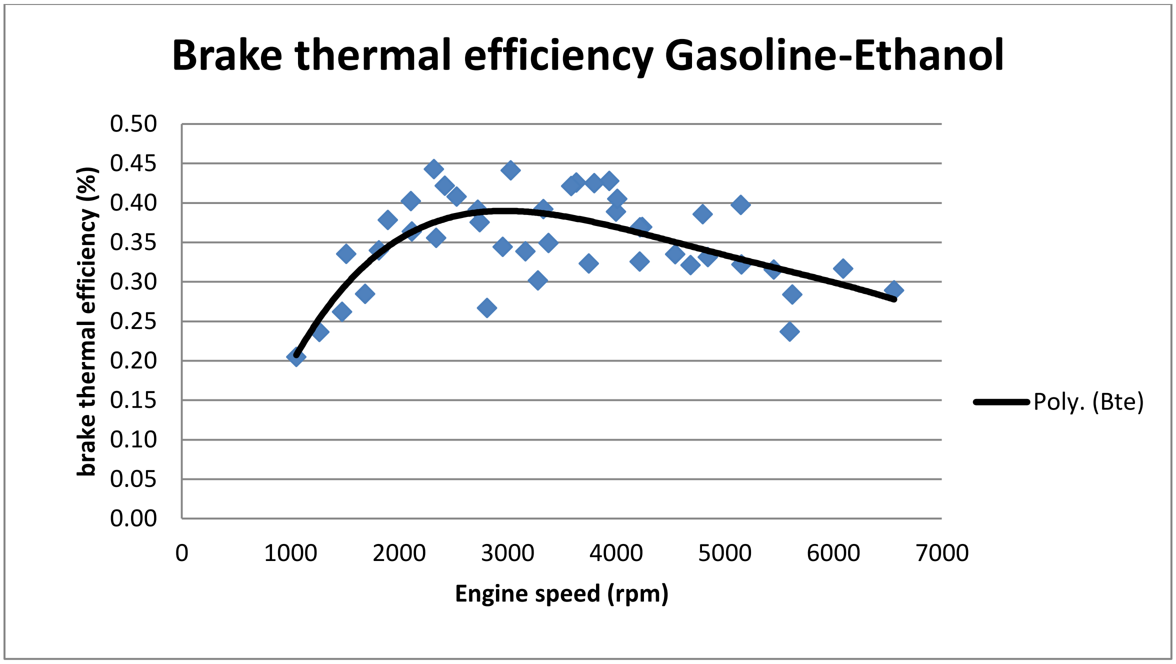


Figure 37: Gasoline- Ethanol blend brake thermal efficiency

When the engine is running on Gasoline- Ethanol blend, maximum brake thermal efficiency of 0.44 is obtained at 2322.1 rpm and the least brake thermal efficiency of 0.20 is obtained at 1055.5 rpm.

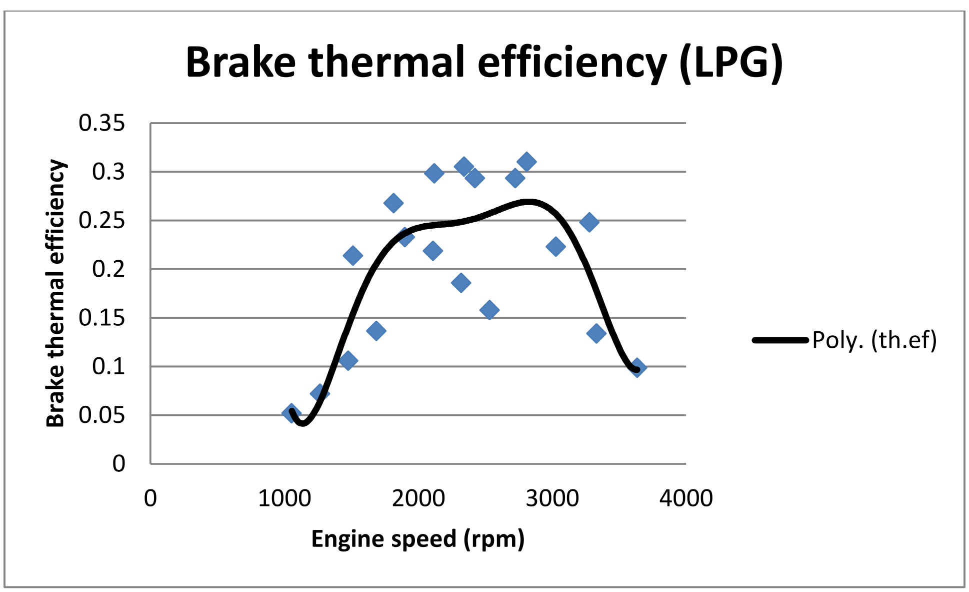


Figure 38: LPG brake thermal efficiency

When the vehicle runs on LPG a maximum brake thermal efficiency of 0.31 is obtained at 3280.49 rpm and the least brake thermal efficiency of 0.05 is obtained at 1055.5 rpm.

From figures 37 and 38 it can be seen that the engine has low thermal efficiency at low engine speed. This mainly is due to thermal losses. The longer hot air spends in a cylinder, the more time it has to heat the cylinder and its components and be lost that way.

On the intake stroke a relatively cooler air is admitted to the cylinders. The longer this cooler air spends in a cylinder, the more time it has to heat up and oppose piston's upward motion on the compression stroke making gas pumping challenging. The gas pumping is to be made at the expense of engine power and hence affects brake thermal efficiency at low engine speed.

At high engine speeds, brake thermal efficiency drops. One reason for this could be the shortened time available for combustion. As engine speed increases, the exhaust valves open sooner leading to greater heat loss with the exhaust. This is evident by the high exhaust gas temperature at high engine speed operation.

LPG operation has registered a higher than Gasoline- Ethanol blend efficiency at 2811.58 rpm. This could be regarded to the fact that gaseous fuel mixes well with air, producing a homogeneous mixture that can be ignited from corner to corner releasing its energy.

The least brake thermal efficiency is also registered by LPG operation. A brake thermal efficiency of 0.05 is achieved at 1055.5 rpm. This could be due to comparatively longer time for fuel leakage from the cylinder. At low engine speed, there is longer time for leakage to the crankcase past the piston rings; there is also longer time for leakage past the exhaust valve during valve overlap. The leakage past exhaust valve during valve overlap of low speed operation is evident from the higher HC emission of LPG shown at figure 27. These leakages are less in Gasoline- Ethanol blend which is supplied as fine droplets to the cylinder compared to LPG, which is vapor when supplied to the cylinders.

The brake thermal efficiency results obtained can shortly be summarized as follows:

- Although LPG was found to have the largest brake thermal efficiency of 31%, its average brake thermal efficiency is 18%. Gasoline- Ethanol blend on the other hand has a maximum brake thermal efficiency of 44% and average brake thermal efficiency of 32%.

The LPG brake thermal efficiency is proved to be highly unstable showing the larger variation from minimum to maximum. Both fuels have their best brake thermal efficiency at medium speeds, and therefore it is advisable to run such fuelled engines mostly on the medium speed range. Speeds from 2322.1 to 3029.285 are where both fuels have better brake thermal efficiency.

4.7 Cost analysis

4.7.1 Conversion cost

Below listed are the costs incurred while Gasoline engine fuel system to use LPG.

LPG regulator and mixer	=1500 Birr
LPG cylinder with gas and outlet valve	= 2200Birr
Hose and connectors	=250Birr
Pressure gauge	=300Birr
Electric wires and connector	=200Birr
Labor	=400Birr
Total	=4850Birr

4.7.2 Gasoline- Ethanol blend running cost

The mass of Gasoline- ethanol blend consumed to cover one kilometer is computed from the data collected by dividing the fuel consumed (gm/hr) by the vehicle speed (km/hr) for each gear. Once the fuel consumed per kilometer is known, the fuel cost per kilometer can be calculated using the current market price.

Currently the least Gasoline- ethanol blend price is 17.95 birr per liter. One liter of Gasoline- ethanol blend is equivalent to 741 gm. Dividing the mass of 1 liter Gasoline- ethanol blend to the price of 1 liter Gasoline- ethanol blend indicates that 1 gm costs 0.024 birr. Multiplying the Gasoline- Ethanol blend fuel consumption (gm/km) by 0.024 birr provides the running cost (Birr/km); the values thus obtained are presented on table 17.

Table 19: Gasoline- Ethanol blend running cost

Vehicle speed (Km/hr)	Gasoline- Ethanol blend consumption in gm/km							
	1st gear	gm/km	2nd gear	gm/km	3rd gear	gm/km	4th gear	gm/km
25	2.23	321.1	1.58	227.5	1.1	158.4	0.98	141.12
30	2.55	306	2.6	312	1.36	163.2	1.09	130.80
35	3.8	390.8	2.68	275.6	1.47	151.2	1.15	118.29
40			2.7	243	1.4	126	1.29	116.10
45			2.75	220	1.55	124	1.16	92.80
50			2.8	201.6	1.6	115.2	1.17	84.24
55			2.85	186.5	1.89	123.7	1.14	74.62
60			3.12	187.2	1.9	114	1.35	81.00
65			2.9	160.6	1.95	108	1.49	82.52
70			2.8	144	2.19	112.6	1.75	90.00
75					2.3	110.4	1.78	85.44
80					2.48	111.6	1.84	82.80
85					2.06	87.2	1.62	68.61
90					1.83	73.2	1.58	63.20
95							1.75	66.32
100							1.71	61.56
Sub total		1017.9		2158.1		1678.78		1439.41
Average (gm/km) gear		339.33		215.81		119.91		89.96
Average (gm/km)								191.25

On average 1km costs 4.59 birr when the vehicle is driven with Gasoline- ethanol blend.

4.7.3 LPG running cost

The mass of LPG consumed to cover one kilometer is obtained from the data collected by dividing the fuel consumed (gm/hr) by the vehicle speed (km/hr) for each gear. Once the fuel consumed per kilometer is known, the fuel cost per kilometer can be calculated using the current LPG market price.

Currently 12 kg of LPG costs 550 birr. Dividing 550 birr by 12kg indicates that 1 gram costs 0.045 birr. Multiplying the LPG fuel consumption (gm/km) by 0.045 birr provides the running cost (birr/km); the values thus obtained are presented on table 20.

Table 20: LPG running cost

Vehicle speed (km/hr)	LPG Consumption in gm/km								
	2^{nd} gear gm/sec	gm/hr	gm/km	3rd gear gm/sec	gm/hr	g/km	4^{th} gear gm/sec	gm/hr	gm/km
25	0.32	1152	46.08	0.29	1044	41.76	0.14	504	20.16
30	0.28	1008	33.6	0.23	828	27.6	0.15	540	18
35	0.31	1116	31.88	0.24	864	24.68	0.19	684	19.54
40				0.17	612	15.3	0.2	720	18
45				0.32	1152	25.6	0.35	1260	28
50				0.2	720	14.4	0.35	1260	25.2
55				0.35	1260	22.90	0.33	1188	21.6
60				0.31	1116	18.6	0.33	1188	19.8
Sub total			111.56			190.85			170.30
Average (gm/ km) Gear			37.18			23.85			21.28
Average (gm/km)									27.44

On average 1km costs 1.257 birr when the vehicle is driven by LPG.

5. SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

On successful completion, this thesis tried to show one way of answering today's ever increasing demand of alternative energy; this is the use of LPG and Gasoline- ethanol blend fuel as a fuel to power Gasoline engine. A vehicle with carbureted 4 cylinders, 4 stroke gasoline engine was selected for the study. Having installed LPG and Gasoline- ethanol blend fuel system, the performance characteristics of the engine were investigated by running the test vehicle on a dynamometer.

The first part of the research was concerned with performance testing of the SI engine powered with Gasoline- ethanol blend. Once the items necessary for the LPG fuel system have been secured and installed same engine was tested for its performance with LPG. Conclusion is drawn from comparison of thus obtained test results.

5.2 Conclusion

The main aim of the study was to test the performance of SI engine fuelled with Gasoline-ethanol blend and LPG. Based on the research findings the following conclusions and recommendations are drawn.

5.2.1 Based on the emission characteristics

Based on the emission characteristic, it can be seen that LPG emission is better in the speed range of 1500 to 3000 rpm. Therefore, engines running in this speed range can run with minimum emission when fuelled with LPG. For example, engines that are used in highly populated areas where there is a risk of people exposure to polluting exhaust gases, or engines that are used close to houses or engines that are used indoors are better fuelled with LPG. Electric generators, water pumps and other stationary engines operating in medium speed range are better fuelled with LPG to run clean with least emission. This will reduce exposure of people to polluting gases.

5.2.2 Based on the brake torque characteristics

Based on the torque performance characteristics, it can be conclude that LPG performs nearly as good as Gasoline- ethanol blend, if the vehicle is driven on 3^{rd} and 4^{th} gears between the speeds of 25 and 40km/hr. Therefore, LPG fuel system is better to be used on vehicles which, most of their running time, stay in this speed range. For example, taxis and Bajaj's are driven mostly in the proximity of 30km/hr, LPG is a better alternative to be used on such vehicles.

5.2.3 Based on the brake power characteristics

Based on the brake power performance characteristics, it can be seen that LPG is a nice choice for vehicles that are mostly driven within city speed limits. Vehicles that such as taxis, school transport vehicles, automobiles operating in town and others which are mostly driven at speeds in the vicinity of 30km/hr are better fuelled with LPG. If such vehicles are converted to run on LPG, they can provide a comparable power with least emission.

5.2.4 Based on the brake specific fuel consumption characteristics

The brake specific fuel consumption (bsfc) results show that the performance of LPG is better than Gasoline- ethanol blend. From the bsfc result of the experiment LPG is a better alternative solution to drive vehicles operating in towns.

5.2.5 Based on the brake thermal efficiency characteristics

LPG fuels have its best brake thermal efficiency at medium speeds, and therefore it is advisable to use LPG on engines that are run mostly on the medium speed range i.e, speeds from 2000 to 3000 rpm.

5.2.6 Based on the running cost

The research has shown that based on the current Gasoline- ethanol blend and LPG prices, running on LPG is cheaper than running on Gasoline- ethanol blend.

5.3 Recommendation

- The researchers recommended further research to be made on how to do so and how to optimize the performance of LPG fuelled vehicle.
- The researchers recommends conversion of stationary engines such as generators and water pumps operating in medium speed range and vehicles such as taxis, 'bajajs', school

and office transport vehicles and other vehicles that are driven with in the town to run on LPG.

- The researchers also recommends that the government should emphasize importing of LPG fuelled vehicles because LPG has low emission, moderate torque and power output and good bsfc when compared with 10%ethanol- 90% gasoline blend. Since bsfc of LPG is lower than Gasoline- ethanol blend, indirectly there is a cost reduction on the fuel cost for those vehicle use LPG fuel compared to Gasoline- ethanol blend.
- The domestic LPG cylinder is fitted with a valve regulator that will allow only a limited gas supply should be designed properly.
- The time and budget should be improved for the future project work.

5.4 Educational Implication

The objective of the national TVET strategy is to create a competent, innovative, adaptable work force in Ethiopia contributing to poverty reduction and social & economic development through facilitating demand driven. High quality technical and vocational education and training, relevant to all sectors of the economy, at all levels and to all people in need of skills development and transferring new technologies (National TVET strategy MOE, 2006).

Since the industries are the stakeholders of the TVET institutions the progress and drop of industry has an impact on the outcome based training. Intensification of the industries and TVET linkage is very important to provide quality and outcome based training. If industries have equipped with enough machinery and equipment, the training program will be easy and efficient. Through industrial training the enterprise can also develop ownership of the TVET system.

Technical and vocational skill is vital to economic development because it is needed for industrial productivity and profitability, as well as national productivity. Without the necessary technical skills, industry and national growth can be seriously hobbled. Technical and vocational education is of great relevance to the technological and economic status of the nation, such as:

- Technological advance and progression, which naturally lead to economic release and independence
- Appropriate development and proper positioning of the technological and economic power of a nation through appropriate human resource development

- Effective mobility of labor through training and re-training
- Effective handling the issue of transfer of technology and its attendant problems
- Reduction of over dependence on imported products and conservation of the resources that could have been spent in engaging the services of foreign experts.

This project is valuable for our country in minimizing a certain amount of Gasoline- ethanol blend fuel imported and reduces the cost of fuel. Since LPG fuel running cost is relatively low. Currently one liter cost of Gasoline- ethanol blend is 17.95 birr, but the cost of one kg LPG is 45.83 birr. This project also summarizing the major courses taken during the master's program, provide the chance to use some special machines, equipment and tools and assuring the rightness of educational policy that the government implementing. It also in line with technology adaptation and transfer as required in TVET policy and strategies.

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