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A REVIEW ON PERFORMANCE AND EMISSIONS CHARACTERISTIC OF LPG FUELLED SI ENGINE

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ABSTRACT

The research on alternative fuels has become essential due to depletion of petroleum products and the rate at which earth atmosphere get polluted. Natural gas had long been introduced to the market where application of cleanliness is emphasized. Liquefied petroleum gas (LPG) is one of the members of natural gases and has been declared as the cleaner fuel. LPG is increasingly chosen as the preferred burning fuel for all types of vehicles due to its advantageous fuel properties. LPG has high octane number and can be used at higher compression ratio. The HC and CO found to be less for LPG as compared to conventional fuel for SI engine. The present study is a review of LPG as an alternative fuel for SI engine and its effect on performance and emissions. The factor like compression ratio and ignition timing that affect on efficiency and emission was considered for study. The most of work found in the literature devoted to predict the performance and emission characteristic of LPG fuelled engine at lower compression ratio and little study was found on NOx emission.

KEYWORDS: LPG, Spark Ignition Engines, Dual Fuel Engine, Combustion Characteristics, Performance Characteristics and Emissions

INTRODUCTION

Environmental issues regarding the emission of conventional fuels such as gasoline and diesel are of serious concern worldwide. The standard emission from conventional fuel vehicles are hydrocarbon (HC), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NOx) and particulate matter (PM). These emissions are harmful gases which can have adverse impact on human body and destroy the environment by playing an important role in formation of the greenhouse effect, acid rain and global warming. Therefore, alternative fuels such as natural gas are being considered to replace the role of conventional fuel in order to reduce these harmful emissions from being released to the atmosphere. These alternative fuels may possibly contribute to a significant reduction in emission in most vehicles operating worldwide.

Natural gas had long been introduced to the market where application of cleanliness is emphasized. Liquefied petroleum gas (LPG) is one of the members of natural gases and has been declared as the cleaner fuel. LPG is increasingly chosen as the preferred burning fuel for all types of vehicles due to its advantageous fuel properties. LPG is proven to have lower emission of pollutants such as hydrocarbon (HC), carbon dioxide (CO_2), carbon monoxide (CO) and nitrogen oxides (NOx) if compared to the conventional fuels; furthermore, particulate matter (PMs) is virtually eliminated from LPG vehicle emissions. A lot of researches have been done to prove that vehicles using LPG as the burning fuel shows no decreased in efficiency compared to the conventional fuel operating vehicles along with its advantage of reduction in emission gases from the exhaust of an engine. Besides that, LPG has the capability to reduce the noise from a running engine, helping to effectively decrease noise pollution in urban areas especially during the traffic congestion period. There are currently over 4 million road vehicles using LPG in countries such as Italy, Holland, Japan, the USA, and Australia due to the vast advantages of LPG usage. Due of the abundance of LPG and its important energy and environmental advantages, LPG has been promoted for usage in vehicles. However, the use of LPG requires that fueling, maintenance and storage facilities to be upgraded to a certain standard to ensure the operational safety of its users.

LPG AS AN ALTERNATIVE FUEL

Liquefied Petroleum Gas (LPG) is a mixture of various hydrocarbons and its main components are either propane (C3H8) or butane (C4H10), or combination of the two. LPG is produced as the by-product of natural gas processing or crude-oil refining. Approximately 30% of LPG is produced from oil refining and another 70% is generated from the natural gas processing. LPG is the most widely used alternative fuel in the world, with about 5.7 million vehicles currently using it. LPG exists as gaseous state at atmospheric pressure and room temperature. LPG is a multi-purposed fuel which can be used as the burning fuel in transportation, industrial application, agricultural, leisure industry, cooking and space heating. There are three different grades of LPG available in the market, namely the HD-5 Propane, Commercial Propane and Commercial B/P Mixture. Their compositions are tabulated below.

Table1: Composition of LPG Available in Market

Component	HD-5 Propane	Commercial Propane	Commercial B/P Mixture
Propane	90 % liquid volume (min)	Propane and / or propylene	Butanes and / or butylenes with
Propylene	5 % liquid volume (max)	-	propane and / or propylene
Butane and heavier HC	2.5 % liquid	2.5 liquid	-
Moisture content	Dryness test of NGPA	Dryness test of NGPA	-
Residual Matter	0.05 ml	0.05 ml	-
Pentane & heavier HC			2 % liquid volume (max)
Total sulfur	123 PPMW	185 PPMW	140 PPMW

Properties of LPG

LPG has been and continued to be the most widely used alternative burning fuel. Listed below are some characteristics of LPG

1. LPG is a colorless gas regardless of its state. Chilled water vapor condensed from the surrounding air will appear as white cloud around the LPG leakage point.
2. LPG is odorless or has no smell. Stench agent such as Mercaptan is added before delivery to detect leakage. Mercaptan additive has an unpleasant and foul smelling so that leak can be easily detected.
3. LPG is chemically reactive and will cause natural rubber and some plastics to deteriorate. Hence, it is advisable to use equipment specifically designed for LPG
4. LPG is highly volatile and flammable. Thus, it must be stored in a high ventilation rate area and kept away from any sources of ignition.
5. LPG is a high performance fuel. It can burn when the fuel to air ratio is between 1:10 and 1:50 range.
6. LPG vapor is denser than air. Propane is about one and a half times as heavy as air. Any leakage of LPG will sink to the ground and accumulate in low lying areas due to its high density property. Hence, LPG is not advisable to

be stored in basements. Although LPG is non-toxic, it has an anesthetics effect when present in high concentrations. Therefore, LPG should always be kept away from children whenever possible.

Table 2: Properties of LPG

Characteristics	Propane	Gasoline
Chemical formula	C_3H_8	C_8H_{18}
Boiling point (◦C)	-44	30-225
Molecular weight (kg/Kmol)	44.1	114.2
Density at 15 ◦C kg/l	0.507	0.705
Auto ignition temperature (°C)	480	285
Octane number (RON)	112	91.8
Octane number (MON)	99.5	89
Stoichiometric air fuel ratio (kg/kg)	15.6	14.7
Upper Flammability limits in air (% vol)	74.5	7.6
Lower Flammability limits in air (% vol)	4.1	1.3
Lower calorific value (kJ/kg)	46.365	42.1

Features of LPG for Engine Application

1. The cost of LPG is less than that of gasoline and available in abundance.
2. LPG has a comparable performance if compared to the conventional fuels with lower pollutant emission.
3. LPG is friendly to the environment. It produces less pollutant to the atmosphere with virtually no particulate matters (PM), low level of carbon monoxide (CO), hydrocarbons (HC), and oxides of nitrogen (NOx). LPG emits less greenhouse gases (GHG) compared to any other fossil fuel when measured through the total fuel cycle.
4. LPG is used in commercial and domestic heating; it is portable because it is stored in steel tanks which are easily transferred to other places.
5. LPG has a very good safety record over the years. The conversion kits readily available in the market enable LPG to continue being a widely used road fuel
6. Researchers have shown that engine maintenance is reduced significantly because LPG does not wash the lubricant oil from the cylinder walls or dilute the oil. Hence, engines using LPG as the burning fuel always enjoy a longer service life and reduced maintenance costs.

Limitation

Although LPG has a great deal of advantages, it has some limitations too as listed below

1. LPG is a non-renewable fossil fuel. If we use LPG faster than the rate of its generation, it will begin to deplete.
2. LPG is denser than air, and may pose a risk when leakage occurs as it will accumulate in low-lying areas.
3. A bulky storage tank is needed to store LPG. Hence, larger boot area is required to place the storage tank in place. The heavier storage tank also reduces the storage capacity and may cause inconvenience.
4. It was revealed that there exist a number of countries with underdeveloped technologies for LPG distribution system and therefore, limits its usage. LPG is only used in residential homes as heating and cooking gas.
5. The contents of propane in LPG are different for most countries. For instance, LPG contains more than 90 % propane in UK, whereas in Italy the level can be as low as 20% and 70% in India. This fluctuation proves to be a barrier to standardization of LPG vehicles around Europe and the rest of the world.

Safety Issue

Studies of have shown that LPG has a safe record if compared to other conventional fuel vehicles. LPG had been proven to be the safest fuel with the lowest accident rate throughout Europe. However, LPG does pose a different type of risk due to its natural properties when a leak occurs. LPG is a highly volatile fuel and pressure gradients will cause the leaking LPG to discharge fast enough to result the liquid LPG to evaporate before reaching the ground. Higher quantities of LPG spill will produce a boiling pool on the ground and LPG will continue to evaporate until there is no more left. Hence, LPG has the highest pool burning rate due to its active vaporization. The potential of LPG to cause an accidental explosion is almost twice compared to gasoline since LPG vapor has a higher tendency to be in contact with an ignition source due to its high volatile properties. Normally, LPG is delivered to the storage station by tanker trucks. Correct settings of the pressure valve are a crucial element in the delivery process so that no leakage of LPG vapor occurs in an unusually warm day. The containers are of special design at 45 °C with a safety factor of 4:1. The design pressure used is 18.25bar since vapor pressure of commercial LPG is 17.76bar at the corresponding specific temperature. As a result, the tanker trucks possess a higher capability to resist the mechanical forces associated with an accident if compared to other conventional fuel transportations.

The possibility of LPG leaks at joints and fittings is also higher as LPG fuel is transported at a higher pressure. There is a great safety risk associated with the transfer of LPG from tanker trucks to the storage as LPG vapor will be released on disconnection when there is any human error. Luckily, LPG is odorized with the foul-smelling agent such as Mercaptan for easy detection of any leakage. However, LPG is denser than air and it will accumulate in the low lying area if there is inadequate ventilation. Under this condition, leakage of LPG may go undetected. Thus, as a safety precaution to avoid gas build-up, LPG vehicles are not allowed to enter underground car parks. For safety issues associated with fire hazard during storage, LPG is stored in above ground tanks with thick gauge steel in the storage station. Natural circulation of air and the odious agent Mercaptan help to reduce the dangers of leakage in the weaker point of the LPG storage system such as joints, connection, and fittings. The major safety concern in the storage is the external heating from fire plus the failure of the pressure relief system which will lead to pressure build-up in the tank. This will cause a fatal explosion and therefore, regular checks should be performed on the pressure relief devices to reduce the tendency of pressure build-up in the tank.

PERFORMANCE AND EMISSION CHARACTERISTIC OF LPG FUELLED

Some of experimental and analytical result are discussed below to review the performance and emission characteristic of LPG fuelled

T. Yusuf et. al(2005) present the experimental result using LPG as fuel to evaluate the quality of air in Malaysian night market. In Malaysian night markets or "Pasar Malam" in the Malaysian language are huge pen markets, which convene once or twice a week in certain locations in every neighborhood. Electrical engine generators using gasoline as fuel are used as a source of electricity in these markets. The generators exhaust emission and high density of people in the market cause the air quality at the market places to deteriorate. In this work engine modifications were kept to minimum in order to reduce the conversion cost. Experimental engine test showed that the engine running on LPG fuel system delivered a comparable brake power and torque in comparison with the conventional fuel. Conversion of a sample of these engines using LPG as fuel showed that the average reduction of exhaust gas emission was about 36% for CO_2, 38% for CO and 79% for NOx in comparison to the original fuel.

Syed Yousufuddin, Syed Nawazish Mehdi(2008) evaluates the performance and emission characteristics of a single cylinder, 4-stroke, air-cooled, variable compression ratio spark ignition engine when fuelled with LPG at compression ratios like 7:1 and 10:1 at constant speeds (2500 and 2800 rpm), with varying loads. The results obtained show that the engine running on an LPG fuel system delivered a substantial improvement in power and torque in a high-load condition. Conversion of the engine using LPG as fuel showed an average reduction of CO and HC exhaust gas emissions in comparison to the original fuel.

K F Mustafa, H W Gitano-Briggs(2008) presents an experimental investigation of a Liquefied Petroleum Gas (LPG) fuelled four-stroke spark ignition engine. The engine used in the study was originally a four-stroke spark ignition gasoline engine and minor modifications were carried out to permit the experiments to run on LPG fuel. The result shows that the level of carbon dioxide (CO_2) peaked at around relative air-fuel ratio of 1.0 and carbon monoxide (CO) exhibits a sharp decreased as the relative air-fuel ratio increases. Unburned hydrocarbons (UHC) also shows marked reduction as the relative air-fuel ratio exceeds stoichiometric and nitrogen oxides (NOx) exhibits an increasing trend as the relative air-fuel ratio increases.

Andrzej Kowalewicz(2000) presents a study of LPG lean burn in a motorcycle SI engine. The lean-burn limits are compared by several ways. The relations of lean-burn limit with the parameters, such as engine speed, compression ratio and advanced spark ignition, etc., are tested. The experimental results show that larger throttle opening, lower engine speed, earlier spark ignition timing, larger electrode gap and higher compression ratio will extend the lean-burn limit of LPG. The emission of a LPG engine, especially on NOx emission, can be significantly reduced by means of the lean- burn technology.

N. Seshaiah(2010) experimented with variable compression ratio spark ignition engine. The engine has been tested with pure petrol, LPG, and petrol blended with ethanol 10%, 15%, 25% and 35% by volume. Also the petrol is blended with Kerosene at 15%, 25% and 35% by volume. Brake thermal and volumetric efficiency variation with brake load was compared. Result shows that the LPG is a promising fuel at all loads lesser carbon monoxide emission compared with other fuels tested.

R.K. Mandloi et. al(2010) studies the use LPG instead of gasoline. Result shows that LPG reduces the engine volumetric efficiency and, thus, engine effective power. LPG decreases the mole fractions of CO and NO included in the exhaust gases. But in Long term continuous use of auto- LPG causes thermal Pitting of engine the part which leads to increase engine pollution. Along with this it was suggested that structural failure may take place due high cylinder pressure and temperature.

S. Murillo et.al(2005) carried out experimental research with use of LPG in spark ignition outboard engines. The result obtained indicate that with the use of LPG, specific fuel consumption, CO_2 and CO emissions were much lower without noticeable power loss but in contrast, NOx emissions were much higher.

Badr, N. Alsayed and Manaf(1998) presents the experimental results of a parametric study on lean operational limits of Ricardo E6 Engine using propane and LPG as a fuel. The result had shown that the spark timing have a significant influence on engine lean limit, the research has taken out the results for only first misfire criteria for two speeds only. The study covered a wide range of engine parameters; namely: engine speed (900±3000 rpm), spark timing (0±40^0 BTDC), compression ratio (6±16), intake temperature (25±150 ^{0}C), intake pressure (0±40 kPa), and relative humidity of intake air (30±95%).They investigated that, as the spark timing was advanced, both lean knocking and misfiring limits were reduced.

when the compression ratio was increased, the misfiring limit of LPG and air mixtures showed some decrease while those of propane air mixtures changed only a little.

Lean knocking limit, on the other hand, decreased sharply with the increase in compression ratio. For a given spark timing of the LPG fueled engine, the lean misfiring limit increased with increasing engine speed up to about 2000 rpm beyond which the misfiring limit either decreased or remained almost the same. Moreover, the lean knocking limit increased monotonically with the speed. For the propane-fuelled engine, the spark timing was adjusted to advance with the speed. In such a case, the engine speed showed relatively minor effects on the misfiring limit. Moreover, as the engine speed was increased the lean knocking limit decreased till 2000 rpm beyond which it showed a slight increase.

F. N. Alasfour(1998) investigated the effect of varying ignition timing on NOx emission, exhaust temperature, knock occurrence and thermal efficiency in a spark ignition engine. A Hydra single-cylinder, spark-ignition, fuel injection engine was used with a 30% Iso-butanol gasoline blend as fuel. Results show that retarding ignition timing causes the exhaust temperature to increase. For a lean mixture, advancing ignition timing has a great effect on the increase of the level of NOx, while for a rich mixture advancing ignition timing has a minimal effect. Advancing ignition timing showed the peak of NOx emission to be shifted towards the lean fuel air equivalence ratio. Preheating inlet air increases the knock intensity and causes the knock to occur at less advanced ignition timing. Retarding ignition timing causes the engine thermal efficiency to decrease.

Hakan Bayraktar, Orhan Durgun(2005) investigated the effects of LPG on spark ignition engine combustion and performance A quasi-dimensional spark ignition (SI) engine cycle model was used to predict the cycle, Governing equations of the mathematical model mainly consist of first order ordinary differential equations derived for cylinder pressure and temperature. Combustion is simulated as a turbulent flame propagation process and during this process, two different thermodynamic regions consisting of unburned gases and burned gases that are separated by the flame front are considered. A computer code for the cycle model has been prepared to perform numerical calculations over a range of engine speeds and fuel–air equivalence ratios. In the computations performed at different engine speeds, the same fuel–air equivalence ratios are selected for each fuel to make realistic comparisons from the fuel economy and fuel consumption points of view. Comparisons show that if LPG fueled SI engines are operated at the same conditions with those of gasoline fueled SI engines; significant improvements in exhaust emissions can be achieved. However, variations in various engine performance parameters and the effects on the engine structural elements are not promising.

J.A. Yamin a, O. Badran b(2002) analytically studied a propane powered 4-stroke spark ignition engine to minimize the heat losses. The effect of the equivalence ratio, compression ratio, spark plug location, and combustion duration at different speeds on the heat losses has been studied and result of analytical study shows that engine design and operating parameters have an effect on the percentage heat losses from the engine. Increasing compression ratio, the need for near-central spark locations, larger valve areas and the aim for leaner air–fuel equivalence ratios are shown to have a favorable effect on reducing heat losses, though care must be taken to avoid knocking. It was concluded that the increase in percentage heat losses reduces the cylinder peak pressure and temperature, causing the engine power to drop because a lesser fraction of the thermal energy ends up as useful work.

CONCLUSIONS

From above literature it can be concluded that LPG is suitable alternative for SI engine. But the performance and emission characteristic of LPG fuelled engine was studied at lower compression ratio. And it was observed that engine output decreases. As is known, LPG has a high octane number. Thus, it may lead to operating with higher compression ratios, and consequently, the engine efficiency and fuel economy would be better than those determined here. LPG has negative effect on volumetric efficiency and NOx. The maximum cylinder pressures and temperatures predicted for LPG are higher. This may cause some damages on engine structural elements. The exhaust gas emission such as HC and CO for LPG fuelled engine is less as compared to gasoline fuelled engine.

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