LPG Review

INTRODUCTION

LPG (Liquefied Petroleum Gas) is a petroleum derived, colorless gas, typically comprised of mainly propane, butane, or a combination of these two constituents. LPG fuel for vehicles is actually a mixture of various hydrocarbons which are gases at atmospheric pressure and temperature but which liquefy at higher pressures like less than 200 psi. LPG is a natural derivative of both natural gas and crude oil.

Commercially three different grades of LPG are available, Table 1. Standard HD5 requires minimum propane content of 90 % and propylene content of less than 5 % (volume basis).

Table 1. Composition of LPG Types

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 and heavier HC			2 % liquid volume (max)
Total sulfur	123 PPMW	185 PPMW	140 PPMW

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*PPMW: Particles per million by weight fraction.

The remainder is normally n-butane, with isobutane and butanes also present. The limitation on propylene and other unsaturated hydrocarbons (olefins) results from their low octane number which means low knock resistance, Table 2.

Table 2. Octane numbers of LPG Components and gasoline

Component	Formula	Research Oct. Num.	Motor Oct. Num.	Est. max. ratio compr.
propane	C_3H_8	111.5	100	11:01
n-butane	C_4H_{10}	95	92	8:01
isobutane	C_4H_{10}	100.4	99	9:01
propylene	C_3H_6	100.2	85	7.5:1
n-butane-1	C_4H_{10}	100	80	6.5:1
n-butane-2	C_4H_{10}	101	83	7:01
regular gasoline	C_8H_{18}	92-95	83-86	9:01

Source: [6]

A second concern with propylene is its photochemical reactivity, which is higher than that of propane. This could be an important factor in formation of smog. Propylene does not occur in LPG obtained from natural gas processing plants but it is available in the LPG resulting from petroleum refinery operations. The minimum propane requirement is due to the necessary of sufficient vapor pressure in order to deliver fuel to the engine, even at very low temperatures, Figure1 and 2 . Vapor pressure of butane is considerably less than that of propane at any given temperature and will not provide adequate pressure for proper equipment operation below about 18-19 C (a minimum of about 0.2 Mpa absolute pressure is required for satisfactory operation of delivery system) LPG has been and continues to be the most widely used alternative fuel to gasoline and diesel on the worldwide basis. The popularity of LPG as an alternative fuel over the years provides its place in the clean air programs. There are over 500,000 vehicles using propane gas in the United States, most are spark-ignition engines adopted to use either

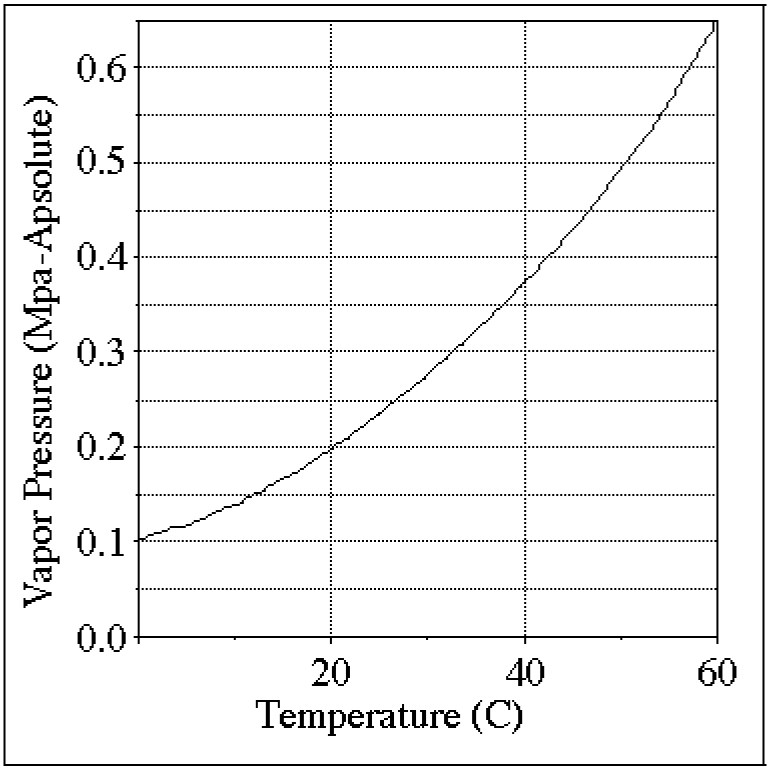

Figure 1. Vapor Pressure of Butane

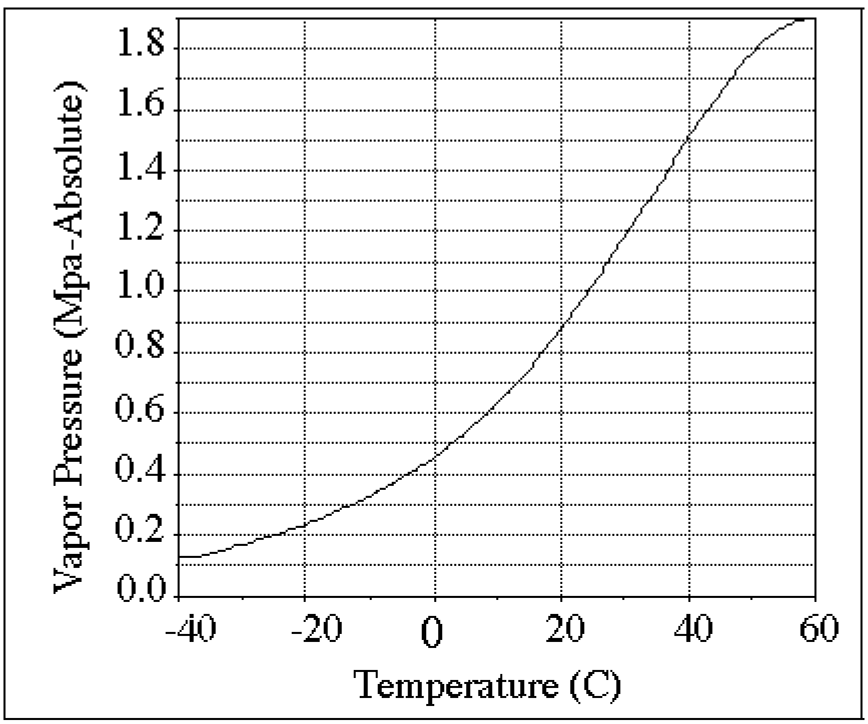

Figure 2. vapor Pressure of Propane

propane or gasoline. 300,000 of them are operated by commercial fleets and are used for hauling products, personal carriers, busses, airport shuttles, forklifts.[4]

High octane rating of propane provides that optimized propane engines would be more efficient than that of equivalent gasoline engines. Although there are no optimized propane engines available in U.S, research in this area is presently being supported by the U.S Department of Energy. According to this program, an optimized propane engine will be developed to install in a Chevrolet Lumina (or equivalent vehicle). Chrysler Canada has also developed a propane fueled van with an optimized engine design. These vehicles will reportedly be available beginning with the 1995 model year. [4]

There are over 2,500,000 vehicles running on propane worldwide.[12], Table 3.

Table 3. Estimated Worldwide Distribution of LPG Vehicles

Country	LPG
Australia	200,000
New Zealand	50,000
Canada	140,000
Mexico	435,000
Netherlands	700,000
Korea	160,000
United States	500,000
Worldwide	2,500,000

Source: NREL

Approximately 30 % of the LPG production in U.S.A is generated during oil refining and 70 % is from natural gas processing and reserves. Propane is removed from natural gas due to the difference between their boiling points (-42 C for propane -162 C, for methane). This could cause some problems because of the liquefaction of propane under high pressure when natural gas is pumped through the pipelines with compressors.

U.S. Domestic production accounts for over 85 % of the LPG supply [10]. The State of Texas produces 34 % of the Nation`s supply of LPG and has 57 % of the underground storage capacity. According to LPG industry, domestic LPG supply is sufficient to economically supply 21 million vehicles in 2000, 12.5 % of U.S automobiles.[12] Projections by the California Energy Commission, Table 4, for near future shows that LPG prices increase more slowly than gasoline [12].

Table 4. Projected 2000 Fuel Prices of LPG and Gasoline

	Gasoline $ gal. equivalent	LPG $ gal. equivalent
Wholesale	0.93	0.52
Retail	1.39	0.98

Source: NREL

In the United States there are more than 10,000 retail propane refueling stations, many of which are located in the southwest and western states, whilein Canada there are about 5,000 stations. Ferrelgass, the second largest propane retailer in the US, operates a fleet of 2,400 vehicles. Of those 2,300 are dedicated propane vehicles, consisting of medium-duty trucks and light-dutypickups.[13] A survey which was achieved in 1992 among 118 fleet managers with an average of 449 vehicles in each fleet, propane was by far the most attractive fuel as shown in Table 5 [Schmidt]

Table 5. Alternative fuels selected by fleet managers (Percent)

	Propane	CNG	Electric	Methanol
Business	86	14	29	0

Utility	71	36	36	14
Goverment	77	22	33	11

In the United States, the propane industry has attempted to adopt an automotive propane standard known as HD5. [1] Fuel for spark ignition engines must meet comply with requirements as set out in the HD5 specification. The standard is not universally observed because the concentration of actual propane ranges between 50-100 % depending upon location. Much of the remainder of the gas is butane and some other hydrocarbons, both saturated and unsaturated. The composition of LPG as an automotive fuel varies in a broad range from one country to another, depending on the cost and availability of the fuel in relation to alternative fuels, especially conventional fuels, gasoline and diesel, Table 6

Table 6. LPG Composition (% by volume) as Automotive Fuel in Europe.

Country	Propane	Butane
Belgium	50	50
Denmark	50	50
France	35	65
Greece	20	80
Ireland	100	-
Italy	25	75
Netherlands	50	50
Spain	30	70
Sweden	95	5
United Kingdom	100	-
Germany	90	10

Source: Urban 1982

IC ENGINE EFFICIENCY WITH LPG

Volumetric efficiency determines the maximum power that can be developed by the four stroke cycle engines due to their distinct induction process. In another word, volumetric efficiency indicates the ratio of the volume flowrate of air inducted to the intake system to the rate at which volume is occupied by the piston. Volumetric efficiency of propane is worse than gasoline. Theoretical reduction in volumetric efficiency can be calculated from combustion equation at stoichometric air-fuel of mixture. Stoichometric means the minimum amount of air that supplies sufficient oxygen for the complete combustion of all the fuel. No free oxygen would appear in the products of tailpipe emission.

$$\eta_v = \frac{2(m_a + m_F)}{\rho_i V_d R_s}$$

η_v : Volumetric Efficiency

m_a : Mass Flowrate of Air

m_F : Mass Flowrate of Fuel

ρ_i : Intake Manifold Air Density

V_d : Displaced Volume

R_s : Engine Speed

$$0.9\,C_3H_8 + 0.05\,C_3H_6 + 0.05\,C_4H_{10} + 5\,(O_2 + 3.76\,N_2) \Rightarrow 3.05\,CO_2 + 4\,H_2O + 19\,N_2$$

Low density of HD5 propane causes approximately 4 % power loss (which is the ratio of the volume of fuel to the volume of fuel / air mixture) compared with only the value of % 1.72 with gasoline powered engine. Introduction of gaseous fuels in the intake manifold decreases the air partial pressure notably compared to gasoline. This reduction in power is inherent the structure of gaseous fuels.

- One way to compensate this loss is to use supercharger or turbocharger in order to increase air flowrate. Superchargers and turbochargers provide more power fom the engine by compressing the inducted air higher density than ambient. Volumetric efficiency goes up with turbochargers and superchargers along with better brake specific fuel consumption. Turbocharger has a turbine and compressor in a common shaft. Turbine is driven by the exhaust gas. The using of exhaust gas provides the recovery of waste energy which leads the increase in the overall efficiency. An intercooler or aftercooler is applied in order to provide further increase in the combustion air density. Supercharger is operated on the same principle with turbocharger. But the driven of compressor is achieved by engine's crankshaft. Turbo lag which indicates the delay between boost and throttle response. Because in the event of sudden increase in power demand, turbine must achive this. This can be a problem in spark ignition engines. However this is not noticeable in large diesel engines. The drawback with supercharger appears in cruise conditions. Because supercharger can not adjust itself to this condition due to direct connection to crankshaft as easily as turbocharger can. An electric clutch that turn the supercharger on and off and a by-pass application which takes air from the supercharger output and introduce it in the intake are the current methods for the solution of this.
- Another approach that has been considered is to enrich the oxygen content of the intake air by using a membrane gas separator or other means. The oxygen enrichment approach is under research at the present time and is not available on purchased vehicle.[4]

The second reason which causes power loss is related to the intake manifold air density. Theheat of vaporization of gasoline helps to decrease the temperature of mixture, producing the dense mixtures. Although propane and methane have higher heat of vaporization value, they are already in gaseous state when inducted into the intake manifold and they do not provide this cooling effect. Development of liquid fuel injection systems for LPG engines should provide better performance and efficiency. Besides this liquid fuel injection provides better A/F ratio control . Back-fire is almost eliminated due to introducing less volume of explosive gases in the inlet system. Cooling effect of endothermic expansion of the liquid increase the resistance to pre-ignition and knock. This leads higher compression ratio which means higher power output.

Another loss off volumetric efficiency and power is related to alternative fuel conversion hardware itself. Most engines converted to burn LPG or CNG suffer an additional 10-20 % power loss due to obstruction of air flow.[4] This explains the difference between theoretical power loss and actual power loss. The lower (A/F) ratio for gasoline means that the chemical energy released per kg of stoichometric mixtureburnt during combustion is greater than gaseous fuels (methane and propane) despite the lower heating value of gasoline. The improved volumetric efficiency and higher combustion energy increase the output of the engine. Power tests were done by General Motor Corporation using two 5.7 L engines with standard gaseous carburetion equipment. A comparison of the results showed that 8 % less power with LPG than with gasoline , and 14.6 % less power with natural gas. It also reports that CNG requires 5 degree greater spark advance and that the ignition advance for LPG is approximately the same as gasoline. In spark ignition engines the air and fuel are pre-mixed before introduce into the engine cylinders. When during the compression stroke the resistance of the fuel to the knock , in other words autoignition of the fuel is identified by its octane rating. Knock occurs due to the high temperature and pressure. Knock is a high-pitch, metallic rapping noise. his noise results from rapid-release of energy and accompanying pressure waves that travel across the cylinder under this condition.[16] There may be power loss due to reduction in fuel antiknock rating. Heavy and prolonged knocking may cause significant power loss and damage to the engine. Knock primarily depends on complex physical and chemical phenomena highly irrelevant with engine design and operating conditions. There are two methods available to measure octane rating of fuels : Motor octane number is the better indicator at the full throttle, low engine speed and part throttle, low and high engine speed. Research octane number, is in general the better indicator of antiknock rating for engines operating at full throttle and low engine speed. Antiknock index (the average of RON and MON) is currently accepted method of relating RON and MON to actual road antiknock performance in vehicles.[4] It should be noted that Motor method antiknock ratings best correlate with the order of engine severity of gaseous fuels in actual engines and indeed only a Motor Method test procedure is approved by ASTM for gaseous fuels.[6] Fuel with an antiknock rating exceeding that required for knock-free operation does not improve performance. However fuel knock sensor provides performance improvement as the antiknock rating of the fuel is increased.

Higher compression ratio improves thermal efficiency and provides more power that can be produced by the engine. Higher octane rating of propane compared to gasoline allows higher compression ratio for the engine.

$$\eta_t = 1 - \frac{1}{r^{k-1}}$$

η_t : Thermal Efficiency

k : Specific Heat Ratio (C_p/C_v)

Natural gas and propane are generally considered to reduce engine maintenance and wear in spark-ignited engines. The most commonly cited benefits are extended oil change intervals, increased spark plug life, and extended engine life. Natural gas and propane both exhibit reduced soot formation over gasoline. Reduced soot concentration in the engine oil is believed to reduce abrasiveness and chemical degradation of the oil. Gasoline fueled engines particularly carburated engines) require very rich operation during cold starting and warm up. Some of the excess fuel collects on the cylinder walls, " washing " lubricating oil off walls and contributing to accelerated wear during engine warm up [12]. Gaseous fuels do not interfere with cylinder lubrication.

Engines powered by gaseous fuels are generally considered easier to start than gasoline engines in cold weather. Because gaseous fuels are already vaporized before inducted into engine. However, under very cold temperatures, cold-start difficulty occurs for propane and natural gas. This is probably due to ignition failure caused by very difficult ionization conditions, sluggishness of mechanical components.

Hot starting can cause difficulties for gaseous fueled vehicles, especially in warm weathers. After an engine is shut down, the engine coolant continues to draw heat from the engine, raising its temperature. If the vehicle is restarted within a critical period after shutdown, (long enough for the coolant temperature to rise, but before the entire system cools), the elevated coolant temperature will heat the gas more than normal, lowering its volumetric heating value and density. This would cause mixture enleanment.

Gasoline, shows very little change over the normal temperature or pressure range. Propane, however, is gas at ambient conditions. Its physical properties depend mainly on the temperature and pressure at which they are being stored. There must be space left in a propane fuel tank. As the temperature rises, the volume of liquid increases significantly. Due to this, propane system has some kind of safety fill stop device to prevent tank fills to no more than 80 % to 85 % .This provides room for liquid expansion if the temperature increases after the tank is filled. Due to the low viscosity of propane and its storage under pressure, it may leak through small cracks, pumps, seals and gaskets more readily than gasoline.[11]

PROPANE FUEL SYSTEM EQUIPMENT

Mechanical conversions systems for LPG and CNG are basically identical with some exceptions. Storage tanks are different with LPG system. Vaporizer is necessary in LPG conversion system. In LPG conversion system, high pressure regulator is not necessary.

Electronic conversion systems are also available for LPG.

Mixer

Early propane mixers operated as a conventional venturi-controlled devices in a manner quite similar to gasoline carburetors. Vaporized propane is drawn through a fixed orifice in response to engine air flow. The basic design principles have remained unchanged over 30 years. As intake air enters the engine, a venturi effect is created through the mixer air-valve. This slight pressure drop acts on a spring-loaded diaphragm is proportionally with air flow,. This may be best described as a highly accurate flow meter which controls engine fuel flow as a function of air flow.

Vaporizer

Vaporizer converts the liquid propane to a gas. The primary heat source for this vaporization is engine-jacket water which flows through specially designed water jackets cast into the vaporizer body. It is necessary that propane fuel systems draw from the bottom of the tank rather than the top. If engine feed were drawn from the gas phase, the heavier, higher boiling components in LPG would gradually become concentrated in the liquid phase creating a liquid mass with a for vapor pressure and a high freezing point. This liquid would create various problems in the feel feed system .Therefore, L.P.G systems draw from the bottom of the tank and send the liquid through a vaporizer that is heated by engine coolant.

Regulator

The function of the regulator is to provide precise fuel pressure regulation to the mixer. As demand on the regulator increases with engine load, regulator allows higher flow; demand on system decreases, regulator restricts flow to maintain flow pressure. The high pressure regulator is unnecessary due to low pressure in LPG storage tank.

Fuel tank

Propane fuel tank is installed, along with a refueling port,fuel lines, and pressure safety valves. A filter" fuelock" removes particles that may be present in the propane. Propane tanks are constructed of heavy gauge steel, in compliance with the Boiler and Pressure Vessel Code of the American Society of Mechanical Engineers (ASME) to whitstand a pressure of 1000 psi. Normal working pressures of the tanks vary depending upon ambient temperatures and the quantity of fuel in the tank. Propane systems normally limit the liquid level to 80% of tank total tank volume by a stop fill valve. Common operating pressures are in the range of 130-170 psi. Tanks are equipped with pressure relief valves that will release propane vapors to the atmosphere to prevent tank explosion under abnormally high pressure conditions.

REFERENCES

1. J.E Sinor Consultants, Inc Niwot, CO, Technical Evaluation and Assessment of CNG / LPG Bi-Fuel and Flex-Fuel Vehicle Viability
2. G.A.Karim, "Some Considerations of the Safety of Methane, (CNG), as an Automotive Fuel-Comparison with Gasoline, Propane and Hydrogen operation, " S.A.E Paper N. 830267
3. G.A.Karim and I. Wierzba, "Comparative Studies of Methane and Propane as Fuels for Spark Ignition and Compression Ignition Engines," S.A.E Paper N. 831196
4. Timothy T. Maxwell and Jesse C. jones, Alternative Fuels, SAE Inc., 1995
5. Colin R. Ferguson, Internal Combustion Engines, John Willey & Sons, Inc. 1986
6. James.S. Wallace," Assessment of" First Generation Propane Conservation Equipment," S.A.E Paper N. 892144
7. Fred Hendren, "Propane power for Light Duty Vehicles: An Overview," S.A.E Paper N. 830383
8. Bernie W. Rice, "Evaluation of Automotive Stop Fill Valves for Propane Vehicles, " S.A.E Paper No. 861576
9. Algas Carburetion, Handbook
10. NPGA # 1331, Commercial / Industrial Propane Guide
11. Science Applications International Corporation, Introduction to Alternative Fuel Vehicles
12. B Wilson, Evaluation of Aftermarkets Fuel Delivery Systems for Natural Gas and LPG Vehicles
13. J.E Sinor Consultants Inc, The Clean Fuels Report, November 1992, Volume 4, No. 5
14. Enoch J. Durbin, Understanding emissions levels from vehicle engines fueled with gaseous fuels.
15. Andrea Unich, Reda M. Bata, Donald W. Lyons," Natural Gas: A Promising Fuel for I.C Engines," SAE paper N. 930929
16. R.L.Furley, A.M.Horowitz, and N.J.Schroder, Automotive Gasoline. C.H.Jewitt, S.R.Westbrook, D.L.Ripley, and R.H.Thornton, Fuels for Land and Marine Diesel Engines and for Nonaviation Gas Turbines.
17. Roberta J. Nichols, The Challange of Change in The Auto Industry: Why Alternative Fuels?.
18. American Gas Association, Natural Gas Vehicles.
19. John B Heywood, Internal Combustion Engine Fundamentals, Mc Graw-Hill Inc., 1988
20. Herbert Aly and Gunter Siemer," Experimental Investigation of Gaseous Hydrogen Utilization in a Dual Fuel Engine For Stationary Power Plants," ICE-Vol.20
21. K.S Varde, " Propane Fumigation in a Direct Injection Type Diesel Engine," SAE Paper N. 831354
22. Ulrich Oester, James S. Wallace, " Liquid Propane Injection for Diesel Engines" SAE Paper N. 872095
23. W. A Goetz, D. Pethric and T. Topaloglu, " Performance and Emissions of Propane, Natural Gas, and Methanol Fuelled Bus Engines, " SAE Paper N. 880494
24. Fred Hendren, " Propane Power for Light Duty Vehicles: An Overview," SAE Paper N. 830383
25. Nils-Olof Nylund and Matti Kyto " Propane Fueled Heavy-Duty Vehicles," SAE Paper N. 932817
26. John P. Latusek and Robert W. Burrahm, " Conversion of Two Small Utility Engines to LPG Engines to LPG Fuel," SAE Paper N. 932447
27. Edward Bass, Brent Bailey and Steve Jeager, " LPG Conversion and HC Emissions Speciation of a Light-Duty Vehicle," SAE Paper N. 932745
28. R. Sierens, " An Experimental and Theoretical Study of Liquid LPG Injection," SAE Paper N. 922363
29. Reginald F. Webb and Paul J. Delmas, " New Perspectives on Auto Propane as a Mass- Scale Motor Vehicle Fuel," SAE Paper N. 911667

30. Edward J. Farkas, Brian J. Hambleton, " Automatic Stop Fill Technology for Alternative Fuels," SAE Paper N. 952438