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LIQUEFIED PETROLEUM GAS AS AN ENGINE FUEL

by

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INTRODUCTION

For over fifteen years liquefied petroleum gas (LPG) has been used as an engine fuel but only to a limited extent. Most of the demand has been for use in industrial applications and as a fuel for domestic purposes. In recent years, our reserve of LPG has increased, and the potential availability of this product far exceeds the present demand. As LPG is a satisfactory engine fuel when used in the proper equipment, attempts are being made to increase its use for this purpose.

SOURCES

Liquefied petroleum gas is a general term applied to any hydrocarbon gas or mixture of gases that may be liquefied by application of moderate pressure. There are four main sources of these LPG hydrocarbons, (1) natural gas wells, (2) crude oil wells, (3) gas distillate wells, and (4) refinery operations. For the purpose of this discussion, the first three sources may be considered together, since their products are comparable and are composed principally of propane and n-butane, with somewhat lesser quantities of isobutane and other gases. Refinery operations also give a product containing these compounds, along with propylene and butylenes. The following chart (1) lists the hydrocarbons from each source, arranged in the order of increasing boiling points. When crude petroleum is processed in a refinery, about 10 percent of the crude is converted to gases in the LPG range (2). This material is called the "C_3-C_4" cut; its composition depends on several factors. Much of the C_4 material and some of the propylene are used to manufacture additional gasoline by alkylation or polymerization. Some of the butane is added directly to gasoline to give it "front-end" volatility, which improves its starting ability. Motor gasolines contain about 6% butane, on the average.

Normal boiling point °F	Natural source		Refinery source
-259	methane	Gases	methane
-155			ethylene
-128	ethane		ethane
-54		Liquefied Petroleum Gases	propylene
-44	propane		propane
+11	isobutane		isobutane
20			isobutylene
31	*n*-butane		*n*-butane
21 to 39			butylenes
82	isopentane	Liquids	isopentane
68 to 101			pentenes
97	*n*-pentane		*n*-pentane
above 96	heavier		heavier

It is seen therefore that the bulk of LPG available consists primarily of propane and the butanes, the ratio of these depending on the source. Frequently propane is the predominating constituent of commercial products. However, any LPG hydrocarbon may be separated from the mixture by fractional distillation.

PHYSICAL PROPERTIES

The physical properties of pure and representative commercial grades of propane and butane that have a bearing on their suitability as engine fuels are listed in table 1, together with some data on an average regular grade summer gasoline.

The properties listed for the commercial grades are for representative examples, and variations in these properties are to be expected in products from different sources. Commercial propane from a refinery source may contain a considerable proportion of propylene.

It is at once apparent that LPG is different from gasoline in several ways. At ordinary temperatures and pressures, gasoline is liquid, while LPG is gaseous. When it is liquefied, LPG has a considerably lower specific gravity than gasoline. Gasoline has a slightly lower heat of combustion, on a pound basis. However, due to its greater density, a gallon of gasoline contains 20 to 40% more heating value than does a gallon of LPG. The high octane number of the LPG fuels makes them perticularly desirable if they are used in engines designed for high octane fuel. Consideration of these properties of LPG show that it could not be used to best advantage in an ordinary gasoline engine, and that certain changes in the engine are needed to realize good performance from these fuels.

ADVANTAGES AND DISADVANTAGES OF LPG AS AN ENGINE FUEL

Volatility

Although LPG has a lower heat of combustion than gasoline on a liquid volume basis, the heat value of its chemically correct gas-air mixture is almost identical with that of gasoline. If the same weight of either mixture were burned in an engine at a fixed compression ratio, the same output would be expected from both fuels. However, gasoline enters the induction system as a liquid and is partially vaporized during the time it is being mixed with air. This vaporization causes a drop in temperature of 20° to 50°F, which allows more air (and fuel) to be inducted per cycle. LPG. being readily volatile, is vaporized before mixing with air and no drop in temperature occurs when the mixture enters the manifold. Therefore the charge of fuel and air that enters the cylinders is reduced, and with it, the maximum power that can be developed by the engine. This lowering in induction efficiency is greatest in engines with heated intake manifolds. It follows that much of the loss in efficiency may be recovered, if the induction system of a standard gasoline engine were to be replaced by one designed for LPG.

On the other hand, the fact the LPG is completely vaporized before it reaches the engine is one of its merits. Gasolines must be carefully blended to give suitable volatility in various sections of the country and at different seasons of the year. However, the volatility of LPG is essentially constant over a very wide range of climatic conditions. Even in the coldest weather no unvaporized fuel is present in the engine cylinder, to leak past the piston and dilute the crank-case oil.

When gasoline enters the manifold, it is only partially vaporized. The liquid portion is in the form of droplets, and as it passes through the manifold there is a tendency for these droplets to settle out along the way. Thus some of the cylinders receive leaner charges than others. This lack of uniform distribution tends to lower the output of the engine. With LPG as a fuel, all cylinders receive charges of equal concentration, since all

Table 1

PROPERTIES OF GASEOUS FUELS

	Pure Propane	Pure n-Butane	Commercial Propane (2)	Commercial Butane (2)	Gasoline Summer 1950
Boiling point, °F at 1 atm	-43.73 (3)	+31.10 (3)	-51	+15	99-404 (4)
Specific Gravity liquid 60/60	0.5077 (3)	0.5844 (3)	0.509	0.582	0.737
Density, lb/gal. at 60°F	4.233 (5)	4.872 (5)	4.24	4.84	6.135
Heat of combustion					
Btu/lb	21,490 (3)	21,134 (3)	21,560	21,180	20,280
Btu/gal	90,752	102,774	91,500	102,600	124,500
Air required for combustion lb air/lb fuel	15.65 (2)	15.43 (2)			
Flammability limits vol % in air mixture	2.1 to 7.4 (6)	1.6 to 6.5 (6)	2.4 to 9.6	1.9 to 8.6	1.3 to 6
Vapor Pressure, psig (2) at:					
60°F	92	12			
100°F	174	37	192	59	8.3 (4)
130°F			286	97	
Octane Number motor method	97.1 (7)	90.1 (7)			78.2 (4)
Octane Number research method	+1.9* (7)	93.6 (7)			83.5 (4)

* Equal to isooctane (100 octane number) plus 1.9 ml of tetraethyllead per gallon.

the fuel is vaporized. This advantage of near-perfect distribution does not completely offset the disadvantages of low heating value and induction efficiency, and a given engine will burn a considerably larger volume of LPG fuel than gasoline for the same power output (8,9).

However, if a comparison of the two fuels is made on the basis of their heats of combustion, rather than on the volume of fuel consumed, one finds that LPG is equal to, and frequently better than gasoline. This is a result of an increase in the thermal effeciency of the engine when LPG is used as a fuel. For instance, an analysis of data reported by Samuelson (9) shows that the heating value of propane was utilized 3 to 21 percent more efficiently than that of gasoline when burned in an engine with a 5.4:1 compression ratio, with the greatest increase occurring at low loads. The same data show that fuel consumption of propane, on a volume basis, was 33% greater than that of gasoline at maximum load, and 14% greater at low load.

Octane Number

In order to compensate for the lower output with LPG fuels caused by low induction efficiency, advantage may be taken of their high octane number by burning the fuel in a more efficient engine. This may be done either by using a supercharger to get more fuel and air into the engine or by increasing the compression ratio of the engine. No data are available on supercharged LPG engines, but some work has been reported on the use of higher compression ratios. LPG is a high octane fuel, as shown by data in table 1, and will give its maximum performance in a high-compression engine. Samuelson (9) has reported data on the specific fuel consumption of propane and butane in tractors designed to burn LPG fuels. He found that at higher power outputs, a slightly greater volume of propane was necessary to produce the same power in an LPG engine of 9:1 compression ratio than was the case with gasoline in an engine of 6.65:1 compression ratio. As the load was reduced, the relative fuel consumption became more favorable to LPG. At 25% of the rated load, fuel consumption in the gasoline engine was about 12% greater than in the LPG engine. He compared the fuel consumption of propane and butane in engines with compression ratios ranging from 5.4:1 to 8:1, and found that throughout the range, 12 to 15% (by volume) more propane than butane was used for comparable outputs. Most of this increase is accounted for by the difference (11.7%) in the heats of combustion of the two fuels, on a volume basis.

LPG fuel has been used in engines with compression ratios up to 12:1. It has been estimated (10) that engines to burn propane "should be designed with compression ratios of at least 10:1 and that they should give an increase in thermal efficiency of at least 15% in comparison with engines of conventional compression ratios". It should be pointed out that this statement applies to propane. If butane or a mixture of propane and butane are to be used, then the compression ratio probably should be somewhat less, since butane requires a lower compression ratio for knock-free performane.

The compression ratio of an engine may be changed by altering the pistons or cylinder head. However, increasing the compression ratio increases the pressure and temperature developed in the cylinders. This increases the load on the crankshaft, bearings and power transmission line and may cause engine failure. A high-octane fuel such as LPG or aviation gasoline requires an engine matched to the fuel, built with the extra sturdiness needed to withstand the loads imposed by high compression ratio. Some types of heavy-duty truck, bus and tractor engines may be converted for operation on LPG, but conversion should not be attempted without consulting the manufacturer. Some manufacturers of heavy-duty engines offer units designed for LPG fuel, and several thousand of these engines are in use, most of them in the West Coast and Southwestern states.

Other Considerations

It is not necessary to use any additives, such as tetraethyl lead and gum inhibitors with liquefied petroleum gas in order to raise its octane number or inhibit gum formation. Its octane number is naturally high and it contains no gum. Harmful sulfur compounds occurring naturally with LPG are much easier to remove than those present in gasoline. It is an exceptionally clean-burning fuel and leaves practically no deposits in the engine.

One would expect that an engine operating on a high-volatility fuel such as LPG would be easy to start, even in very cold weather. While it is true that a combustible mixture is easily obtained in the cylinder, other factors are involved which may introduce difficulties in starting. A high-compression engine requires more power from the starting motor to turn it over, and at the higher pressure, a higher voltage is necessary to cause sparking from the spark plug. Also, since the oil is not reduced in viscosity by crankcase dilution, it offers more resistance to cranking at low temperature. In converted engines these causes of hard cold-weather starting may be reduced by using 12-volt ignition systems and lighter lubricating oils.

Aside from its low calorific value, the main disadvantage of LPG is that it is normally a gas, and special equipment is necessary for storing and dispensing it under pressure.

LPG FUEL SYSTEM

In a typical LPG fuel system, the fuel is stored in a pressure tank equipped with a pressure relief valve, a special filling valve, and some means of preventing its being filled completely. At least 10% of the volume of the tank should be vapor space to provide room for thermal expansion of the liquid. The volume of liquid propane increases 13.3% if the temperature is raised from 25° to 75°F. Liquid fuel is withdrawn from the bottom of the tank, and flows through a filter to a high-pressure regulator. It is then vaporized in a heat exchanger, which is heated by the hot water from the engine cooling system. After leaving the heat exchanger, the vapor flows through a second pressure regulator to the carburetor, where it is mixed with the proper proportion of air. A complete description of several carburetors, with instructions for their adjustment is given in reference 11.

The National Bureau of Standards has not made tests on any equipment for conversion of engines to use LPG fuels. Raymond (2) has listed five manufacturers of LPG carburetors:

American Liquid Gas Corporation
1109 Santa Fe Avenue, Los Angeles 21, California

Century Gas Equipment Company
Lynwood, California

Dix Manufacturing Company
3447 E. Pico Boulevard, Los Angeles 23, California

Ensign Carburetor Company
7010 S. Alameda Street, Huntington Park, California

J & S Carburetor Company
Post Office Box 5023, Dallas 2, Texas

No claim is made that this is a complete list, and inclusion in the list does not imply that the product is recommended by the National Bureau of Standards.

SAFETY ASPECTS OF LPG MOTOR FUEL

Any hydrocarbon fuel presents a fire hazard. With liquefied petroleum gas, this hazard is great because it evaporates easily and an explosive mixture with air may be quickly attained. It is essential therefore that anyone handling this material have a thorough knowledge of its behavior, and that the equipment used be properly designed and installed. Safety regulations for storing and dispensing LPG are given in the National Board of Fire Underwriters Pamphlet No. 58 (12). This pamphlet gives specifications for approved tanks, pumps, valves, pipes, flexible lines, fittings and electrical equipment. Additional information is included on mounting and supporting tanks, protection of valves and fittings against damage, required distance of storage tank from other installations, and precautions against static electricity and lightning. Directions for handling LPG fuel are also given in reference 13 and 14.

Since LPG is normally an almost odorless gas, small amounts of sulfur compounds are added to it to impart an odor. These odorants are required by law, and are present in quantities sufficient to make leaks from LPG systems apparant before the lower explosive limit of the mixture with air is reached.

Thirty-seven states have regulations regarding storage, handling and use of LPG. In addition, several cities have ordinances controlling its use.

ECONOMICS OF LPG MOTOR FUELS

Approximately 3.3 billion gallons of LPG were marketed in 1950. About two thirds of this was sold for domestic purposes and about 3% was used as an engine fuel in trucks, buses and tractors. However, the potential production of LPG is far greater, and it is increasing steadily. There are several causes for this large potential supply. In the past, large quantities of these gases were burned or otherwise wasted because of a low demand for them, but more recently, interest in conservation of our petroleum resources has stimulated action to prevent this waste. Another factor is that the gas-content of our petroleum reserves has been increasing for several years. It has been estimated that LPG reserves equal 0.8 gallon for every gallon of gasoline (15). This large potential availability of LPG has created an interest in development of new uses.

The retail price of LPG is dependent on several factors including the volume demanded, extent of distribution facilities, and the nearness to a producing area. The price of propane at the present time is 5 to 8 cents per gallon below that of gasoline at the refinery.

The cost of storage and dispensing equipment is considerably higher than that of corresponding equipment for handling gasoline. It has been estimated that these facilities cost $0.60 to $1.00 per gallon of capacity for installations of 6,000 to 30,000 gallons (2).

Although it is not feasible to raise the compression ratio of most current automobile engines enough to warrant the use of LPG fuels, several kinds of heavy duty engines can be converted at costs varying from $350 to $500. Engines that are factory engineered for LPG fuels cost $350 or more above the price of comparable gasoline engines (2). This rather large price differential may be due in part to the rather limited demand for conversion parts and engines.

During the past few years, several thousand farm tractors have been converted to use LPG, many of them without changing the compression ratio. The disadvantage of increased fuel consumption, due to lower heating value per gallon of the fuel, has been found to be offset to a considerable extent by lower fuel prices, less engine wear, elimination of sludge deposits, and other economics in maintenance.

REFERENCES

1. Kramer, Wm. H., "LP gas from the ground up", American Gas Journal, October 1948.

2. Raymond, Leonard, "Liquefied petroleum gas as a fuel for automotive vehicles", Paper No. 535, Society of Automotive Engineers, Inc. 29 W. 39th St., N. Y. 18, N. Y.

3. Rossini, F. D. et al, National Bureau of Standards Circular C-461, "Selected values of properties of hydrocarbons", November 1947 United States Government Printing Office, Washington 25, D. C.

4. Blade, O. C., Bureau of Mines Report of Investigations 4765, (December 1950).

5. Cragoe, C. S., National Bureau of Standards Letter Circular LC736, "Liquid densities of eleven hydrocarbons", (1943).

6. International Critical Tables II 179 (1927)McGraw Hill Book Co., N.Y.,N.Y.

7. Puckett, A. D., "Knock ratings of gasoline substitutes", J. Research NBS 35, 273 (1945).

8. St. George, A. J., "Engine and carburetion equipment requirements for liquefied petroleum gas fuel", Paper No. 549, Society of Automotive Engineers, Inc., 29 W. 39th St., N. Y. 18, N. Y.

9. Samuelson, M. H., "Comparative operating data of tractors using gasoline or liquefied petroleum gas fuel", Paper No. 550, Society of Automotive Engineers, Inc., 29 W. 39th St., N.Y. 18, N. Y.

10. Alden, R. C. and Selim, F. E., "LP-Gas for motor fuel", Paper No 548, Society of Automotive Engineers, Inc., 29 W. 39th St., N. Y. 18, N. Y.

11. Abell, Carl, "Adjusting LP-Gas carburetors", Butene-Propane News, October-December 1949. Also see Bulletin 320, Phillips Petroleum Co., Bartlesville, Okla.

12. Pamphlet No. 58, National Board of Fire Underwriters, 85 John St.,N. Y. 7, N. Y. Also National Fire Protection Association, 60 Batterymarch St., Boston 10, Mass.

13. Anon., "How to unload LP-Gas tank cars", Bulletin 114, Phillips Petroleum Co., Bartlesville, Okla.

14. Mattocks, E. O., "Safe handling of liquefied petroleum gases", Bulletin 315, Phillips Petroleum Co., Bartlesville, Okla.

15. Rugh, K. W. and Benz, G. R., "LPG sales continue to gain in 1950", Petroleum Refiner 30, 69 (1951).

ADDITIONAL REFERENCES

1. Wilson, R. E. and Barnard, D. P., "Chemical hay for mechanical horses", SAE Journal 35, 359 (1934).

2. Barnard, D. P., "Butane as an automotive fuel", SAE Journal 35, 399 (1934).

3. Friend, W. F. and Beckwith, E. Q., "Propane and butane as motor fuels", SAE Journal 36, 36, (1935).

4. Weaver, E. R., "Propane, butane and related fuels", NBS Circular 420 (1939). (discusses LPG mainly as a domestic fuel).

5. Anon, "Diesel and butane forum evokes 'hot' discussion", SAE Journal 47, 76 (1940).

6. Taltersfield, E. E., excerpt form "Development of butane as a motor fuel", SAE Journal 47, 311 (1940)

7. Oberfell, G. G. and Alden, R. C., "Natural gasoline looks ahead", Petroleum Refiner 26, 91 (1947).

8. Denny, L. C. and Wickstrom, H. W., "Butane-propane gases handbook", 3rd ed. (1947), Jenkins Publishing Company, Los Angeles, California. (earlier editions published by Western Business Papers, Inc., Los Angeles, California).

9. Anon, "Liquefied Petroleum Gases", Bulletin 308, Phillips Petroleum Company, Bartlesville, Okla.

10. Alden, R. C., "The availability of LPG for direct motor fuel use", Petroleum Processing 5, 1180 (1950).

11. Barkley, J. J., "Questions and answers on propane and butane fuels", Question and answer handbook No 4, U.S. Bureau of Mines (August 1950).

12. Rugh, K. W., and Mattocks, E. O., "LPG survey", Oil Gas Journal 48, 28 (1950).

13. Browne, A. T., "The economics of propane as an engine fuel", Automotive Industries 104, 4 42 (February 15, 1951).