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INVESTIGATIONS OF THE AUTOMOTIVE USES  
OF LIQUEFIED PETROLEUM GASES

by

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## PREFACE

This paper is a summary of the automotive research on propane and butane utilization done at the Research Council of Alberta from November 1955 to December 1960. Problems encountered in the use of propane, cold weather butane apparatus, and the uses and practicability of burning propane and diesel fuel simultaneously in variable speed engines were investigated.

Grateful acknowledgement is made to the University of Alberta for the co-operation and assistance rendered by its staff, and for the use of its facilities in the laboratories of the Department of Agricultural Engineering. The author wishes here to express his personal thanks for the guidance and encouragement given by Professors F. V. MacHardy and B. T. Stephanson of the Department of Agricultural Engineering during the course of experiments.

In addition, through the kindness of Mr. D. L. MacDonald, Superintendent of the Edmonton Transit System, a Mack Diesel bus and personnel to run it were provided for dual-fuel experiments. On behalf of the Research Council of Alberta the author expresses thanks and appreciation to the City of Edmonton for services rendered.

January 1961

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# INVESTIGATIONS OF THE AUTOMOTIVE USES OF LIQUEFIED PETROLEUM GASES

## INTRODUCTION

One of the effects of extensive oil and gas production in Alberta has been to make large quantities of propane and butane available in this province. These gases are used in three main ways - as fuels in farm and small town dwellings for heating and cooking, as raw materials for the manufacture of petrochemicals and, when liquefied, in an oil recovery operation called miscible flooding in which the LP gas acts as a solvent, being forced through an oil bearing formation, to pick up the maximum residual oil. In Alberta, although a considerable market for LP gases exists in the automotive field, only a small percentage of vehicles have been converted to use propane, and there are no known instances of butane being used as an engine fuel.

The major demand for propane is for heating, and of course is seasonal. Since summer storage of propane is possible but costly, there have been occasions when flaring has been allowed. This difficulty might be solved if the summer surplus of propane could be utilized as a fuel for farm tractors. With this in mind, research was initiated to determine the problems peculiar to Alberta operation of automotive engines. An economic study of the LP gas industry by Wright<sup>10</sup> in 1959 gave support to such a study.

The work began with a study of propane user experience, and continued with mechanism research, followed by a development program to improve these mechanisms and to achieve satisfactory automotive operation. The study of user experience served to focus attention on the important problems, and also was beneficial in making contact with other persons keenly interested in propane utilization. During the course of the research program, several new designs and mechanisms were developed as improvements to the conventional LP gas equipment.

### Study of User Experience

Before beginning experimental work on propane and butane carburetion, a survey of industrial and agricultural LP gas engine installations was made. Also, an LP gas symposium was held in November 1955 for members of the LP gas trade, agricultural implement companies, the Edmonton Transit System, and the Department of Agricultural Engineering at the University of Alberta. The Research Council of Alberta was host to the group and discussions concerned the problems of propane production, distribution, and automotive use. Butane, although not commercially available, was discussed briefly.

Preliminary work had been done by Professor B. T. Stephanson of the Department of Agricultural Engineering in 1950. He had shown the economics of farm vehicle operation with propane to be unsatisfactory, due to price structure at that time, and pointed out that since a tank which could operate a tractor for 10 to 12 hours would

be too bulky to mount on the average tractor, it would be necessary for a farmer to have additional tankage close to his working area and to spend time refuelling. Since that time, with the changes in marketing and increase in dealers, it is his opinion that prices might have become low enough to encourage farm use.

The Edmonton Transit System, through Mr. D. L. MacDonald, was co-operative and helpful in providing practical experience data. Since its first tests with butane were unsatisfactory due to the need for extensive engine and equipment modifications to use butane in cold weather, the System turned to propane. It purchased a number of Twin Coach buses equipped with Fageol 12:1 compression-ratio engines which had proven successful for propane use in Chicago<sup>1</sup>. Thirty-three of these buses were still operating at time of writing and were considered completely satisfactory, especially from the standpoint of maintenance. Edmonton's success in this venture has been exceptional. Other Alberta transport use of propane has been troublesome and costly.

Two Alberta trucking companies which had factory-equipped propane units in service have not been pleased with results. Their most frequent complaint had been overheating, causing engine damage in seemingly inconsistent patterns. Some service mechanics were almost superstitious about carburetor adjustments, or blamed inconsistent performance on fuel quality. Propane was termed a "dry" fuel which did not lubricate, and prevented exhaust valves from becoming properly cooled. Both trucking companies eventually discontinued their propane units, having received no satisfaction from engine manufacturers, whose only remedial suggestion for keeping valves cool was to install a vacuum gauge on the engine manifold and warn the drivers not to allow vacuum to drop below a fixed level.

Aside from interviews with users, the reasons some organizations gave for not using propane were interesting and informative. L. J. Rowley<sup>5</sup> sums up this as follows. "The excuse most often heard as a reason for not using LP gas has been the one of fear of fire or explosion. Since it is a common human trait to fear the unknown, our first job was education and training." This fear still persists among truckers in Alberta.

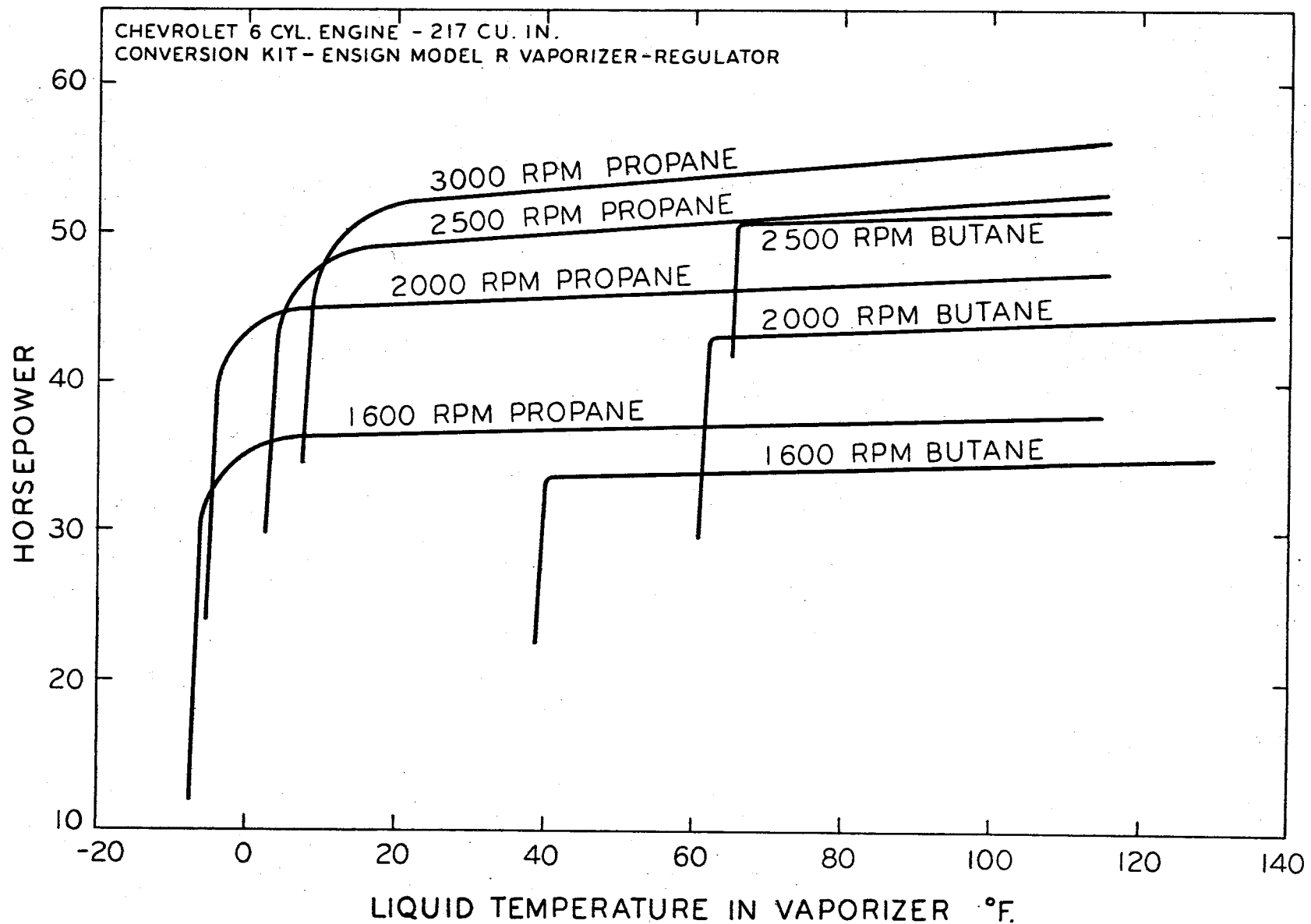
Further talks with a few farmers who owned propane-equipped tractors showed that they liked them especially for "lugging" power at low speeds. The disadvantages cited were difficulty in starting the engines and inadequate service.

#### Research Program Summary

In order to obtain information about some of the problems confronting users, the research program was conducted in several phases:

- A. Tests on a conventionally-equipped propane tractor at the Department of Agricultural Engineering of the University of Alberta to study, (a) power, economy and performance characteristics, (b) temperatures - exhaust, vaporizer, water jacket.
- B. Vaporizer-regulator temperature control experiments<sup>7</sup> on a Chevrolet 217 cu.in.

FIGURE I  
LPG HORSEPOWER CURVES  
VAPORIZER REFRIGERATION EXPERIMENTS



6-cylinder engine equipped with a standard LP gas conversion kit, at the Department of Agricultural Engineering of the University of Alberta.

C. Adaptation of a 1957 Ford 1/2-ton panel truck to the use of butane for cold weather conditions.

D. Dual-fuel tests utilizing propane and diesel, performed on an Edmonton Transit System bus which was equipped with a Mack 4-cycle diesel engine.

E. Dual-fuel studies with a small single cylinder Fairbanks-Morse 45B3-1/8 diesel engine, to obtain optimum mixture conditions.

F. Tests on fuel distribution by Professor F. V. MacHardy<sup>3</sup> were of help during this series on making decisions about the direction of research. Professor B. T. Stephanson carried out experiments<sup>8</sup> to try to find some basic knowledge of the reasons for propane's reputation as a clean fuel which contributes to long engine life, and was assisted by provision of facilities for measurement and evaluation at the Research Council of Alberta.

#### Research Procedure and Results

A. Tractor Tests. Tests were performed at the laboratories of the Department of Agricultural Engineering at the University of Alberta. These laboratories contain engine dynamometers, a number of commercial engines, and suitable engine testing equipment. A commercial propane tractor was belt-connected to the Taylor "Hi-Eff" water brake, and power and economy tests were performed. When operating on propane the fuel consumption was shown to be greater than for gasoline, in ratio of the relative heating values, since propane is a lighter fuel and contains less available heat per gallon.

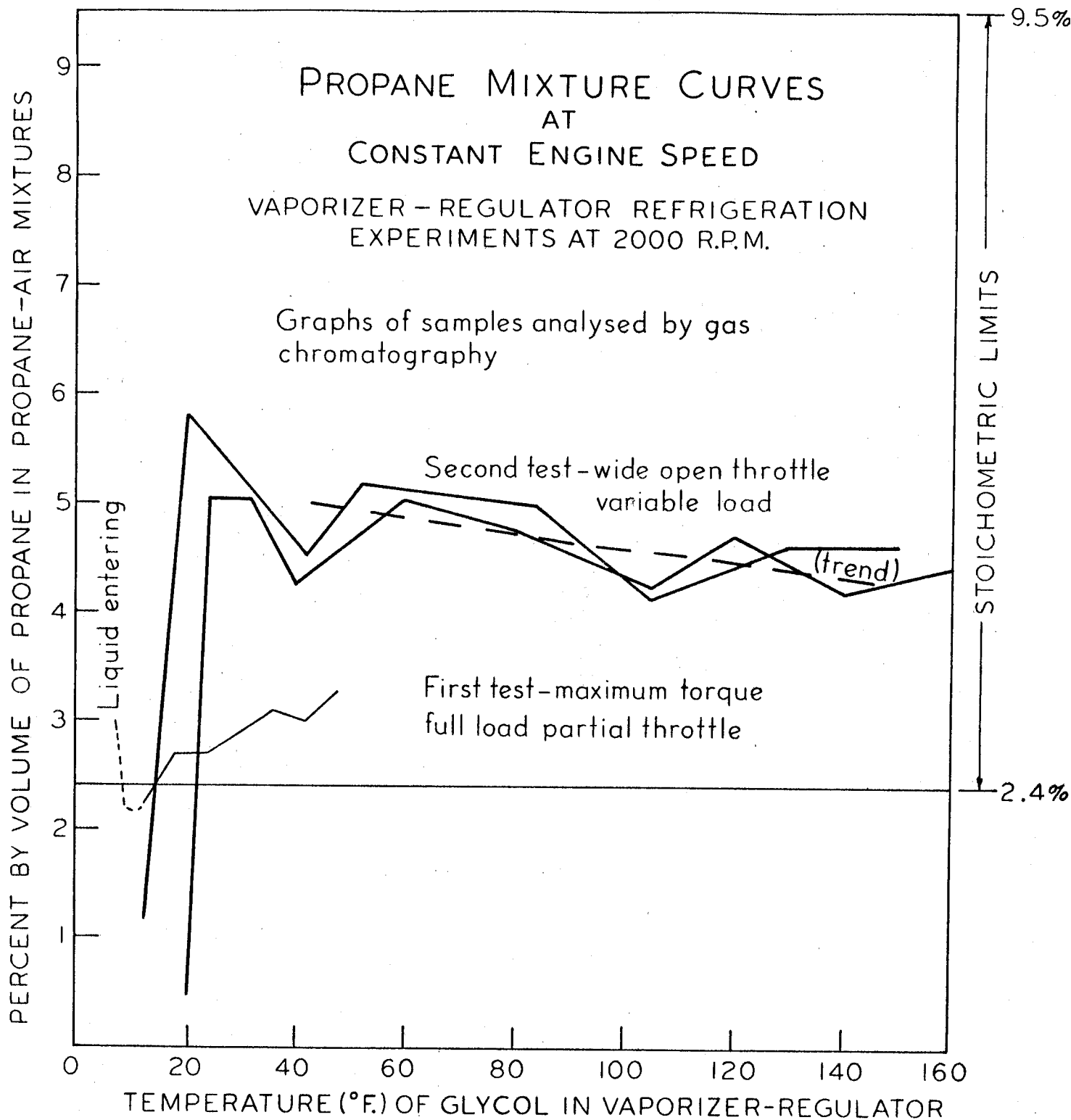
The propane tractor engine was found to exhibit unfortunate "hunting" characteristics at heavy load. After attempting to readjust the governor, attention was centered on the vaporizer, which was apparently allowing surges of liquid propane to pass unvaporized into the carburetor.

Carburetion and governor adjustments and a separate source of heat for the vaporizer were unsuccessful in yielding consistent performance, and this, together with the high exhaust temperatures of 750° to 800°F. obtained, led to a decision to discontinue the tests until more detailed carburetion and vaporizer-regulator studies could be completed.

B. Vaporizer-regulator Temperature Control Measurements. Preliminary work was reported in a previous paper<sup>7</sup>. For clarity, results are shown in figure 1.

A Chevrolet 217 cu.in. gasoline engine was adapted for use with LP gas by a conventional conversion kit (Ensign model R regulator, model XG carburetor). A separate heater circuit was arranged for the vaporizer-regulator. By means of a suitable pump, anti-freeze (ethylene glycol) was passed through the vaporizer-regulator

FIGURE 2



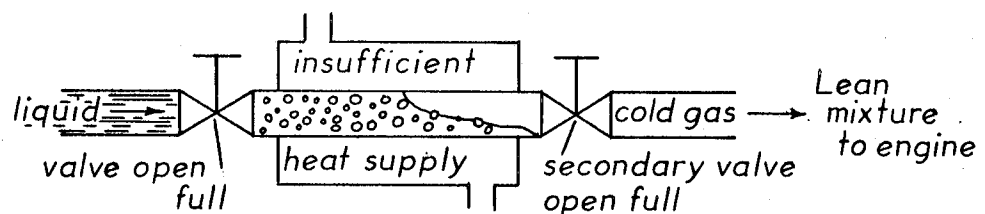


and a heating tank where an immersion heater raised the temperature to 110°F. A stable condition under load was obtained by manual adjustments to throttle and hydraulic brake dynamometer settings. After stability was reached, the throttle setting was fixed and the heater removed from the glycol circuit. This allowed the vaporizer-regulator to take heat from the continuously circulating and insulated glycol solution, causing the temperature in the whole circuit to drop. Speed was maintained by reducing the load as the engine gradually lost power and the vaporizer became colder. Finally, pulses of liquid fuel were drawn into the carburetor, thus flooding and stopping the engine. A transparent tube installed between the vaporizer-regulator and the carburetor enabled the operator to see when liquid droplets were beginning to form, and warned of imminent engine stoppage. In figure 1 temperature measurements were taken from right to left as the test progressed, and corresponding horsepower plotted as ordinate.

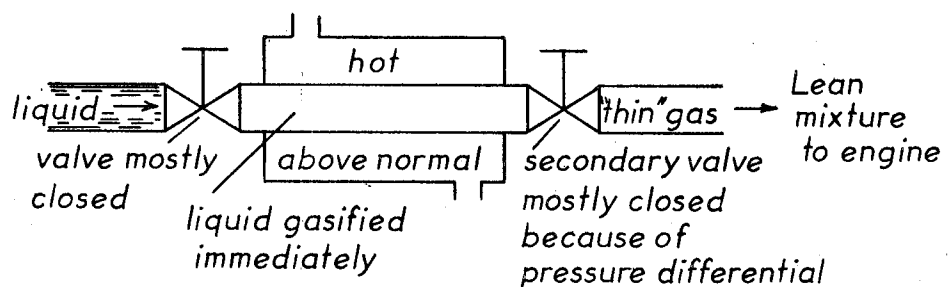
The same temperature reduction procedure was used in further experiments during which samples of the air-fuel mixture being led into the engine were withdrawn and analyzed. A Fisher-Gulf Partitioner, a gas chromatography instrument, was used to measure percentage by volume of propane in air of a number of samples which were drawn from the engine's inlet manifold periodically as the tests progressed. Results are shown graphically in figure 2.

To establish conditions for the gas sampling, it was decided to try to prove or disprove two theories which could account for lean mixtures. These were outlined in a previous paper<sup>7</sup> but are reproduced here for clarity and illustrated in figure 3.

FIGURE 3 EXPLANATIONS OF LEAN MIXTURE PHENOMENON



FIRST THEORY - INADEQUATE HEAT EXCHANGE



SECOND THEORY - OVERHEATED VAPORIZER

"The first theory is that overheating of an engine can [result from a lean fuel-air mixture which can] be caused if the demand for vapour is so great that the heat exchanger cannot supply heat quickly enough, and the vapour passing from the heat exchanger through the secondary pressure control valve has such a low pressure and is so cold that when mixed with the normal amount of air in the carburetor the resulting combination is lean in fuel.

"The second theory is that a hot engine will heat the exchanger so that its internal pressure is relatively high, causing the secondary pressure control valve to allow less weight of fuel to pass into the carburetor." To further explain the second theory it was thought that in a very hot vaporizer the gas density in the intermediate stage (i.e. between the primary and secondary valves) would be relatively low simply by reason of Avogadro's law.

In the first test, which was conducted to test the first theory, the engine was run at full load at 2000 r.p.m. The throttle was opened and load increased until no higher torque could be obtained. Then the load was left constant and the throttle was closed to the point of maximum economy, while maintaining 2000 r.p.m. The heating circuit which had been used to produce the results shown in figure 1 was allowed to refrigerate in the same manner. The fuel system was identical, liquid withdrawal being used so as to cool off the vaporizer-regulator quickly.

As the vaporizer-regulator cooled, speed was maintained by changes to both the throttle and load settings, and performance of temperature to horsepower was similar to that shown in figure 1. As the mixture reached the intake manifold, samples were removed at ten points during the test by a vacuum pump and were compressed into glass sample bottles. Analysis showed a gradually leaner mixture was being obtained at the engine as time progressed and the vaporizer-regulator became colder. These tests were begun at a glycol temperature of 50°F. and continued until the glycol reached 15°F. Results are shown in figure 2 and table I.

Table I. Mixture Composition (by gas chromatography) (see figure 2)

First Test		Maximum torque, full load, partial throttle.									
Sample No.		1	2	3	4	5	6	7	8	9	
Temperature °F.		67	60	48	42	36	30	24	18	12	
% Propane		(2.8)	(3.0)	3.3	3.0	3.1	2.9	2.7	2.7	2.2	
Second Test		Wide open throttle, variable load.									
Sample No.		1	2	3	4	5	6	7	8	9	10
First run											
Temperature °F.		12	20	30	42	52	64	84	105	130	150
% Propane		1.16	5.81	5.24	4.59	5.19	5.13	4.98	4.12	4.61	4.61
Second run											
Temperature °F.		20	24	32	40	60	80	105	120	140	160
% Propane		0.46	5.05	5.04	4.26	5.04	4.79	4.23	4.71	4.19	4.44

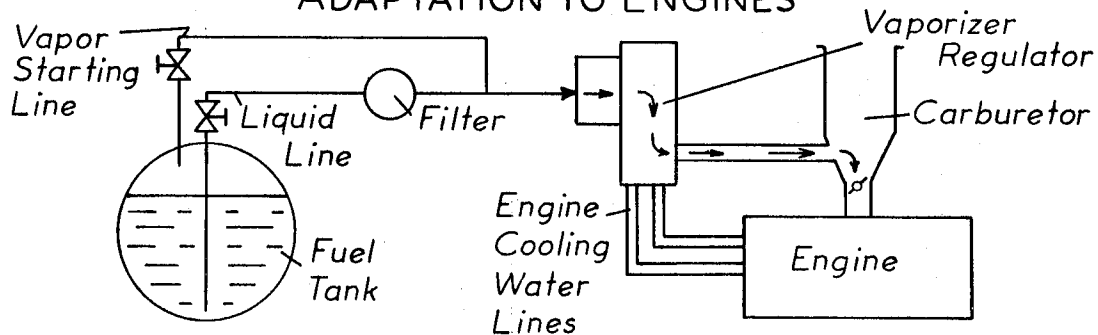
To prove the second theory the ethylene glycol was heated to 160°F. and then allowed to refrigerate. The engine was operated with wide-open throttle in order to eliminate carburetion variables, while speed was controlled by adjusting the torque load. This rather different operating condition did not cause a leaning-out until the lowest temperatures had been reached, but a trend toward leaner mixtures was observed above 150°F. It was deduced that, due to the higher suction in the carburetor compared with the partially-open throttle condition of the first tests, a richer mixture was being drawn by liquid coming over and vaporizing, which accounts for the jump in the curves below 40°F. During this time the engine was difficult to control and keep on a speed of 2000 r.p.m., which strengthens this supposition.

Subsequent tests of the vaporizer at 200°F., with the engine at 1/4-throttle and 1/4-load, showed that although the mixtures became leaner, they did not become dangerously lean. The propane mixture reached a low of 4% under these conditions.

The tests proved the variability of mixtures resulting from variations in vaporizer-regulator temperature. Some of the problems associated with rich or lean mixtures may be blamed on inadequate carburetor adjustment, since it is difficult to adjust by the sound of the engine when a 130 octane fuel is used. However it is the author's contention that most of these problems are caused by inadequate vaporizer-regulator temperature control, and it is his suggestion that manufacturers should now develop suitable constant-temperature devices for this purpose.

C. Adaptation of a Gasoline Vehicle to the Use of Butane for Cold Weather Conditions. Conventional equipment for conversion of gasoline engines to butane will not function properly at temperatures below +40°F. since a considerable vapor pressure is required to drive the butane through the conventional system, and butane's boiling point is +32°F. A diagram of the usual liquid withdrawal technique installed on most factory-equipped LPG engines is shown in figure 4.

FIGURE 4 TYPICAL SCHEMATIC L.P.G. ADAPTATION TO ENGINES



Equipment was designed and tested to function properly under the wide range of temperatures experienced in Alberta. Development experiments were carried out on a half-ton panel truck. To simplify operation, it was decided to keep the gasoline system intact, except for a solenoid-controlled gasoline fuel cut-off, and to build an adapter carburetor for mixing butane with air. Engine speed was to be controlled through the normal gasoline carburetor throttle.

The adapter for mixing butane and air was made with a variable venturi so that it could be adjusted to fit any engine, and thus feed the correct amount of butane with air into the engine. Simplicity of the adapter was emphasized to reduce installation costs, as may be seen from figure 5. Figure 6 shows the complete apparatus for vapor withdrawal of butane for cold weather application. All high pressure lines are short and compact as possible to prevent leaks.

#### Procedure

The procedure followed was to start the engine on gasoline, utilizing the engine cooling water to heat the butane storage tank. When the pressure in the butane tank rose above 15 p.s.i., the operator shut off the gasoline line by the solenoid valve. The gasoline remaining in the carburetor bowl was used up and this was indicated when the engine began to misfire. The butane was then switched on, and operation continued on gaseous butane. Normal control of butane pressure was provided by means of a standard vaporizer-regulator.

The above procedure was reversible, i.e. when the operator wished to return to gasoline operation the butane was switched off, and the gasoline line was opened by the solenoid valve. This would be the procedure when the operator ran out of butane fuel. Since butane may not be readily available at present through normal commercial channels, the installation allows for use of either fuel. When butane is readily available this procedure can be abandoned provided the tank is heated for starting by a conventional engine block heater or other suitable means.

#### Development

A simple 3/4-inch heavy steel pipe was welded into the butane supply tank to serve as a heater. The tank was hydrostatically pressure tested.

An adapter to provide butane gas to the manifold was made according to the drawing shown in figure 5. The bolt and locknut provide a variable venturi action, so that the adapter can fit various engines. An idling system was developed by which it was possible to mount a vaporizer-regulator on the tank, and thus supply low-pressure gaseous fuel in the line from the tank location to the adapter (see figure 6).

The vaporizer-regulator was mounted on the tank frame and the assembly placed inside a half-ton panel truck, where it was bolted to the floor. A short, high-pressure line was run from the vapor withdrawal valve to the vaporizer-regulator, and

FIGURE 5 ADAPTER

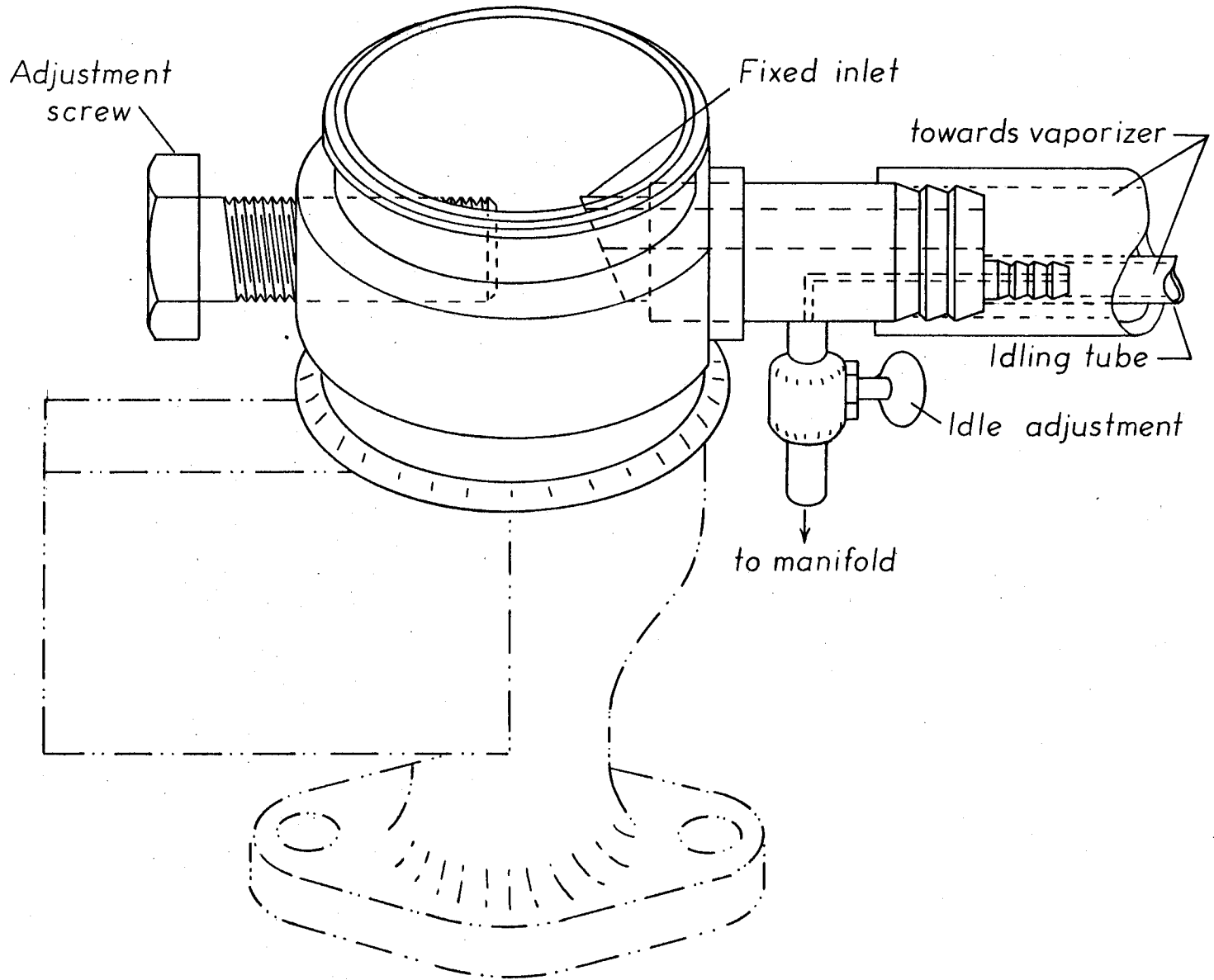


FIGURE 6 VAPOR WITHDRAWAL SYSTEM

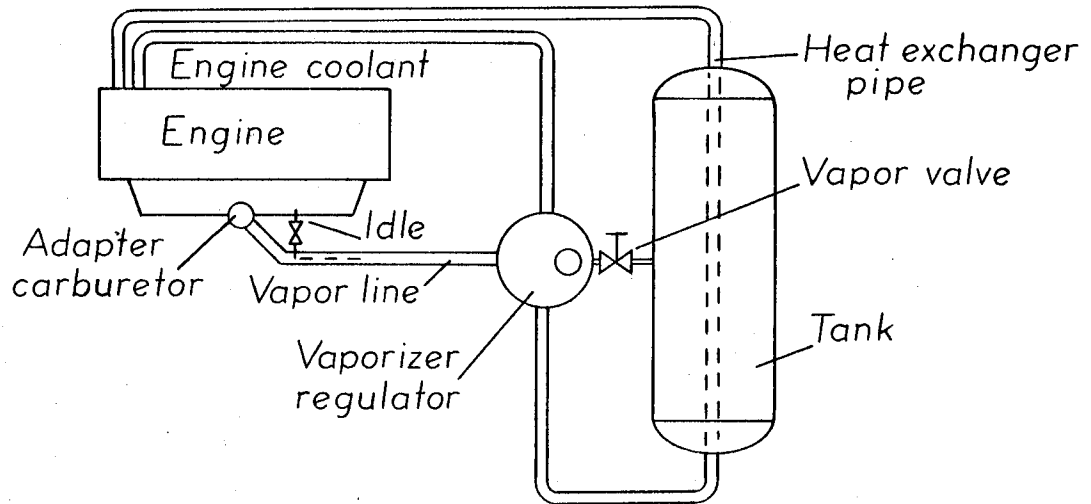


FIGURE 7 IMMEDIATE GASOLINE SHUT-OFF SYSTEM

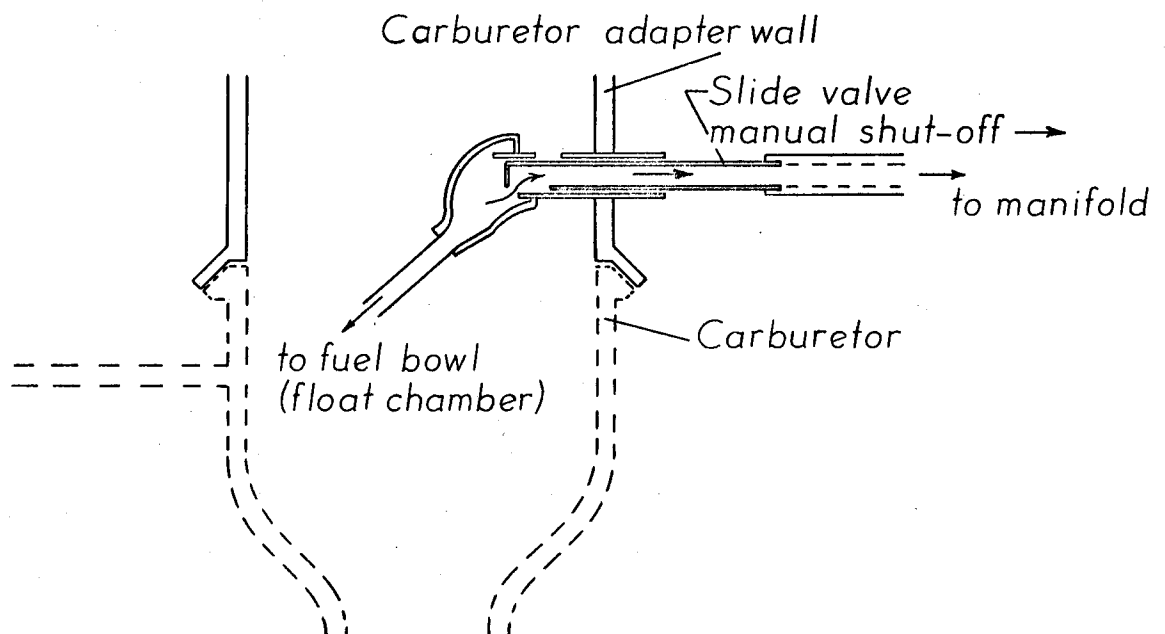


FIGURE 8 BUTANE ACCELERATION PUMP

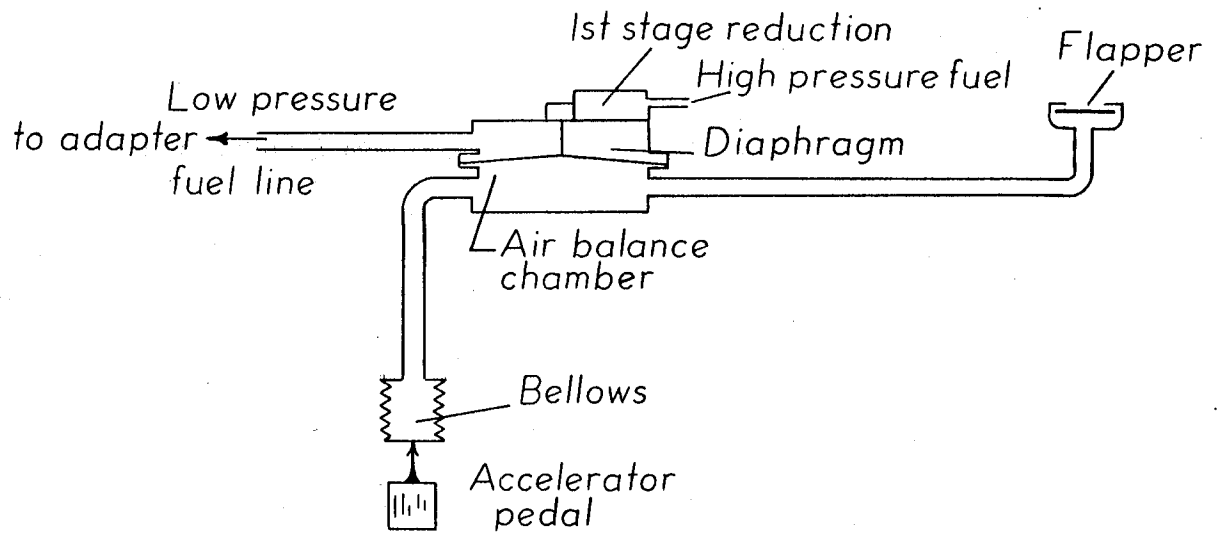


FIGURE 9 REVISED ADAPTER

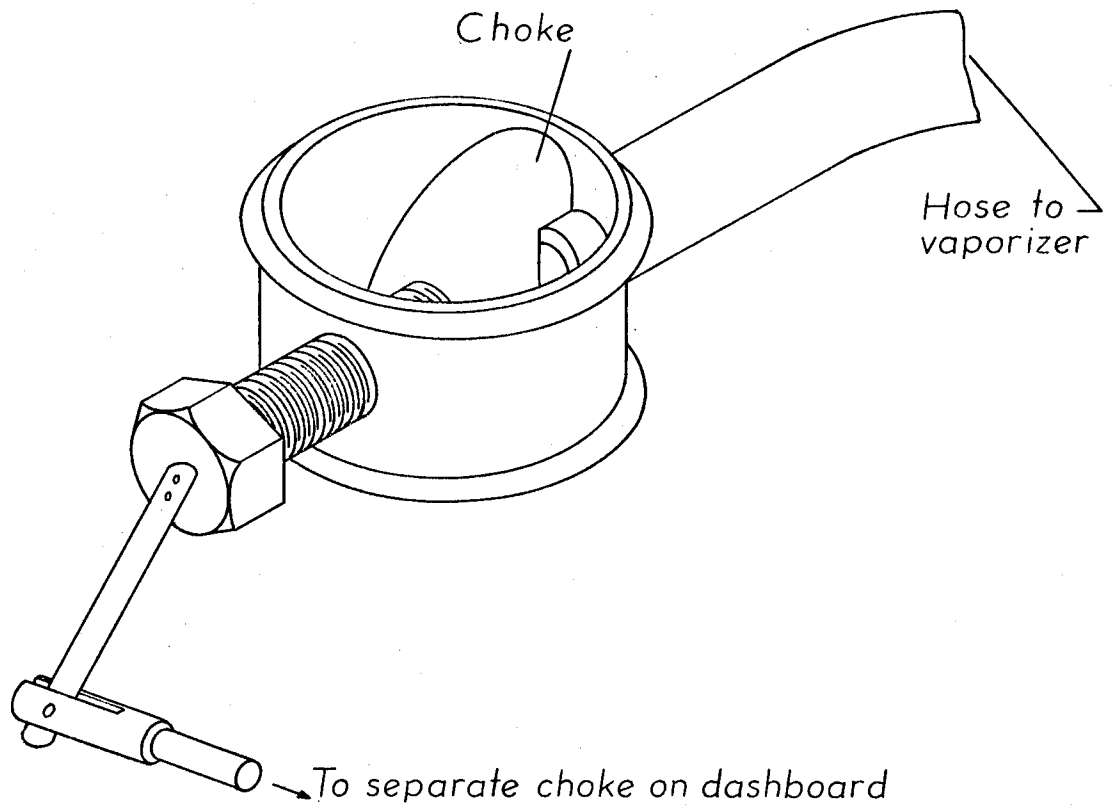
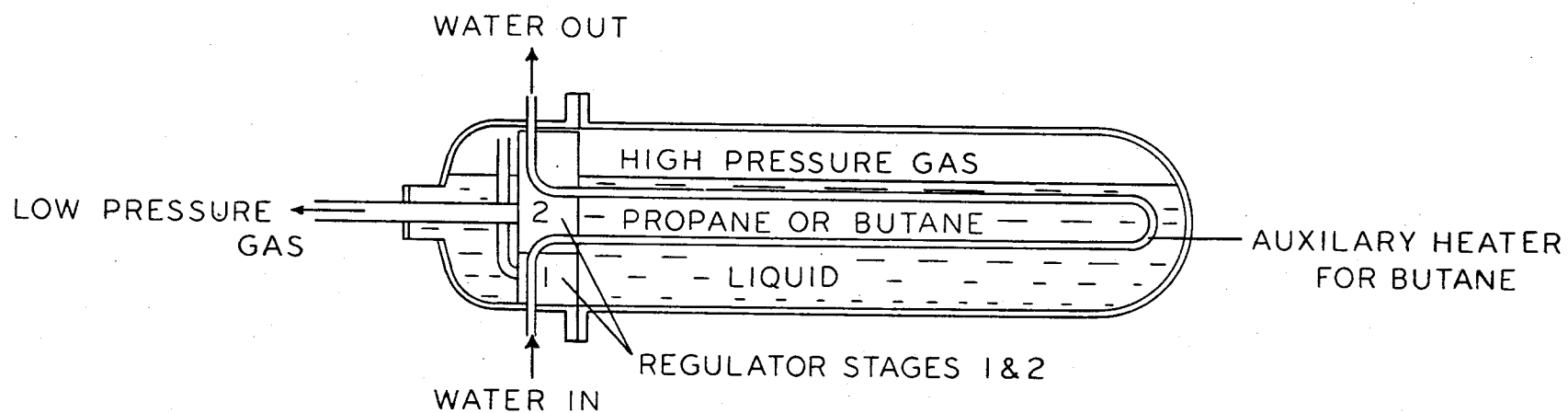


FIGURE 10 SUGGESTED TECHNIQUE FOR L.P. GAS SUPPLY





a twelve-foot length of flexible transparent plastic hose from the vaporizer-regulator through a hole in the floor, under the firewall, to the adapter. Referring to figure 5, it may be seen that air from the throat of the adapter might be drawn back through the supply pipe and into the idle line. To prevent an air short circuit of this kind, the idle line was equipped with about 18 inches of stiff polyethylene tubing which led back inside the main supply tube toward the vaporizer. Hot water was supplied to the tank, and initially for vapor withdrawal, the vaporizer-regulator was considered to be in a warm enough place and to have suitable design to allow normal expansion of butane vapor without causing liquefaction. First tests showed, however, that even when the tank had been well warmed up, the engine demand for fuel was high enough to require heat at the point of pressure reduction (i.e. the regulator). Consequently the vaporizer heating coil was connected in series with the tank heater pipe. The completed adaptation is shown in diagrammatic form in figure 6.

Three problems became obvious during the initial tests. These were: (1) gasoline-to-butane switching took too long to accomplish, (2) the engine would not accelerate easily, and there was a "flat spot" when the accelerator pedal was pushed down quickly and suddenly, and (3) starting directly on butane (after the tank was warm) was difficult without a choke. Use of the simplified adapter made it necessary, when starting, to choke the engine manually by placing one hand over the adapter air intake.

To solve these difficulties it was decided to try an immediate shut-off by connecting the vent of the gasoline float chamber to the intake manifold. By applying the manifold vacuum to the float chamber it was possible to prevent movement of gasoline through the main jets. The venturi action was thus cancelled through a pressure balance; this is shown in figure 7. A slide valve was pulled into position manually by a mechanical link to shut the gasoline off instantaneously. The engine was then kept running by pumping the accelerating pedal until the butane could be turned on. It was expected that suitable acceleration could be achieved by normal use of the gasoline accelerating system; that is, when the accelerating pump was depressed, gasoline and butane would burn together in the combustion chamber. Also, it was expected that the engine would be easy to start on gasoline at any time because the fuel float chamber would always be full.

These expectations were not fulfilled. The new gasoline shut-off system worked well, and caused the desired immediate stoppage of gasoline. A few movements of the accelerator squirted enough gasoline into the manifold to start the motor on butane. However, acceleration was unsatisfactory due to differences in the mixtures. With the above-mentioned apparatus, the resultant mixture was too rich and, instead of making the engine pick up and accelerate, caused an even more critical "flat spot", backfire and muffler combustion. Had this technique been successful, it could have made butane conversion much simpler, by eliminating the three problems listed above. However, it did show that rapid shut-off of the gasoline is possible and, provided the accelerating pump is disconnected at the same time, offers a useful technique for switching over. This particularly facilitates starting, which can be handled on gasoline. The technique may be adaptable to other uses such as a safety shut-off.

It was thought that operational lack of fuel during acceleration (causing the "flat spot") could be eliminated by bringing the vaporizer nearer to the engine. This necessitated the use of a high-pressure line from the tank through the floor, and along the frame to the engine area, where it was connected to the vaporizer. The low-pressure line from the vaporizer to the adapter was a short length of plastic hose. The resultant change in position reduced the "flat spot" considerably but did not eliminate it entirely.

It was decided that a system similar to that of the gasoline accelerating system should be designed. In order to obtain this a pressure bellows was applied to the air balance side of the vaporizer to give an extra boost of fuel as shown in figure 8.

The action of the pressure bellows during acceleration was to increase the pressure within the "Air Balance Chamber", which raised the pressure in the second stage. (Normally this pressure is less than atmospheric). By this means, part of the second stage volume of butane vapor in the vaporizer-regulator was ejected through the adapter system immediately. The second stage thus provided more than the normal amount of fuel, until air, which leaked around the flapper valve, restored the pressure to normal. The results of this cycle proved useful, in that they assisted in priming for starting, although the "flat spot" was still not completely eliminated.

When the vaporizer was close to the engine, the suction required at the variable venturi was reduced, and the engine would run normally with the adjusting bolt on the adapter carburetor almost completely out. In order to obtain better adjustment it was decided to remove the large fixed inlet and to substitute a simple pipe for butane entry, with the inlet of the pipe extending about 1/4 inch into the venturi area. The idling system now consisted of a direct supply to the manifold from a standard idle valve on the vaporizer-regulator.

It was found with this arrangement that the "flat spot" had disappeared, and that rapid, easy acceleration occurred without difficulty. Idling was satisfactory although somewhat sensitive.

The final stage towards satisfactory operation was achieved with the installation of a simple choke for easy starting. This choke was connected to the venturi adjusting bolt, which, in turning through 90° closed off the intake. This assembly is shown in figure 9.

Following this development work, attention was turned to possible improvements in the heating system described previously and shown in figure 6. After trying out an electrical system which involved the use of a separate fan belt-driven 110V generator and a commercial immersion heater, it was decided that the simplest method available, that of using engine cooling water was best. This system utilizes waste heat, whereas the electrical system requires some of the engine's power to drive a generator and is thus inherently less efficient. The basic ideas presented

in figure 6 may be altered to suit the needs of the individual application. Instead of welding a pipe through the pressure tank, it was found just as effective to wind a hose around the butane tank. A commercial adapter\*\* for the carburetor which utilized manifold pressure to give a continuously variable venturi action (and which thus eliminated all idling line problems) performed successfully with this technique, and no "flat spot" recurred when the vaporizer was mounted on the tank at some distance from the engine.

The possibility of having the entire high pressure system enclosed within a tank to ensure safety and adequate heating thus becomes obvious. Regardless of the position of the tank, the only line coming from it would then be a low-pressure line to the carburetor adapter. A suggested scheme is shown in figure 10.

Fuel requirements through all tests were as expected. Comparisons using the butane carburetor (figure 9) described above, the conventional gasoline system and commercial propane adaptor unit, showed that when properly used, butane gives mileage corresponding to its heating value, which is in the ratio of 146,500 B.t.u. per (Imperial) gallon for gasoline, 123,000 B.t.u. per gallon for butane, and 111,000 B.t.u. per gallon for propane (i.e. 1: 0.84: 0.75 respectively)

Subjective impressions were that butane seemed more powerful than gasoline at low speeds, and could not be made to knock or detonate. Mileage checks were also run at -20°F. and proved the suitability of the fuel for use at this temperature. A test run between Edmonton and Calgary and return was conducted without difficulty, using the apparatus shown in figures 6 and 9. The truck performed adequately, showing ample acceleration and smooth idling characteristics.

D. Dual-Fuel Tests on Diesel Bus. This work has previously been reported in detail<sup>7</sup>. In summary the results showed improvement over diesel operation in power and elimination of smoke and unpleasant exhaust odors. The apparatus used for air-propane aspiration and dual control is shown in figure 11. This rather simple method should be useful to those persons wishing to obtain the above mentioned desirable results.

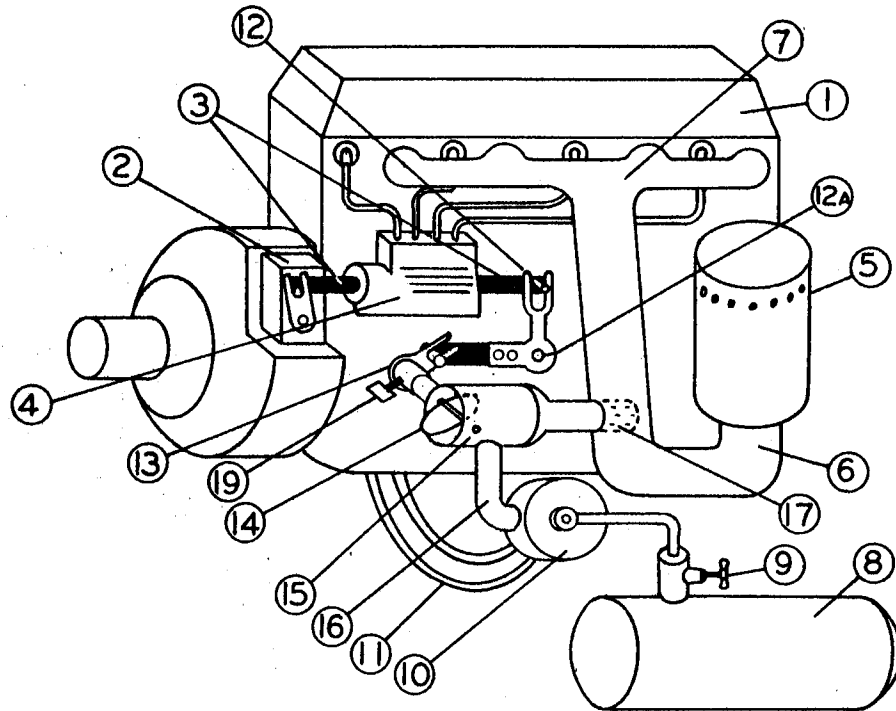
Further work was carried out using one of the commercial kits for dual-fuel conversion. Comparative results are shown in table II. They indicate the practicability of the diesel-propane dual-fuel techniques.

E. Dual Fuel Tests on an Experimental Single Cylinder Engine. Following successful tests of the first dual-fuel bus, it was decided that more information was needed on the proposed carburetion method and on the relation between efficiency and mixture ratios. A small single-cylinder Fairbanks-Morse stationary diesel engine was equipped with a dynamometer built from a Twin-Disc hydraulic clutch, and run to determine its natural characteristics on diesel. Following this, tests were run on propane with the diesel injector linkage adjusted to provide varying proportions of diesel fuel. Results are shown in table III. It appears from these results that power

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\*\* Algas Imperial 300 Mixer.

FIGURE II DUAL-FUEL ENGINE



The diesel engine (1) is controlled in speed by the setting of the governor (2) which moves the rack (3) to vary the amount of the fuel pumped by the fuel pump (4). Air enters the engine through the air cleaner (5), intake pipe (6) and manifold (7).

To supply propane to the engine, a tank (8) valve (9) and pressure reducing vaporizer-regulator (10), (which is heated by engine cooling water through tubes (11)) are supplied. To control the amount of propane fed to the engine a bell crank (12) control pivoted (at 12a) to move a lever (13) rotates the shaft on which a butterfly valve (14) controls the amount of air entering the plenum chamber (15) which in turn controls the air vacuum to draw fuel from the vaporizer-regulator (10) through the connector (16). This vacuum is caused by an insert pipe (17) which operates on the venturi principle as air passes by into the engine. Adjustment (19) controls the position of the butterfly valve (14) relative to the other linkage so that the percentage of propane added is thus variable.

FIGURE 12 DIESEL-PROPANE TEST ENGINE

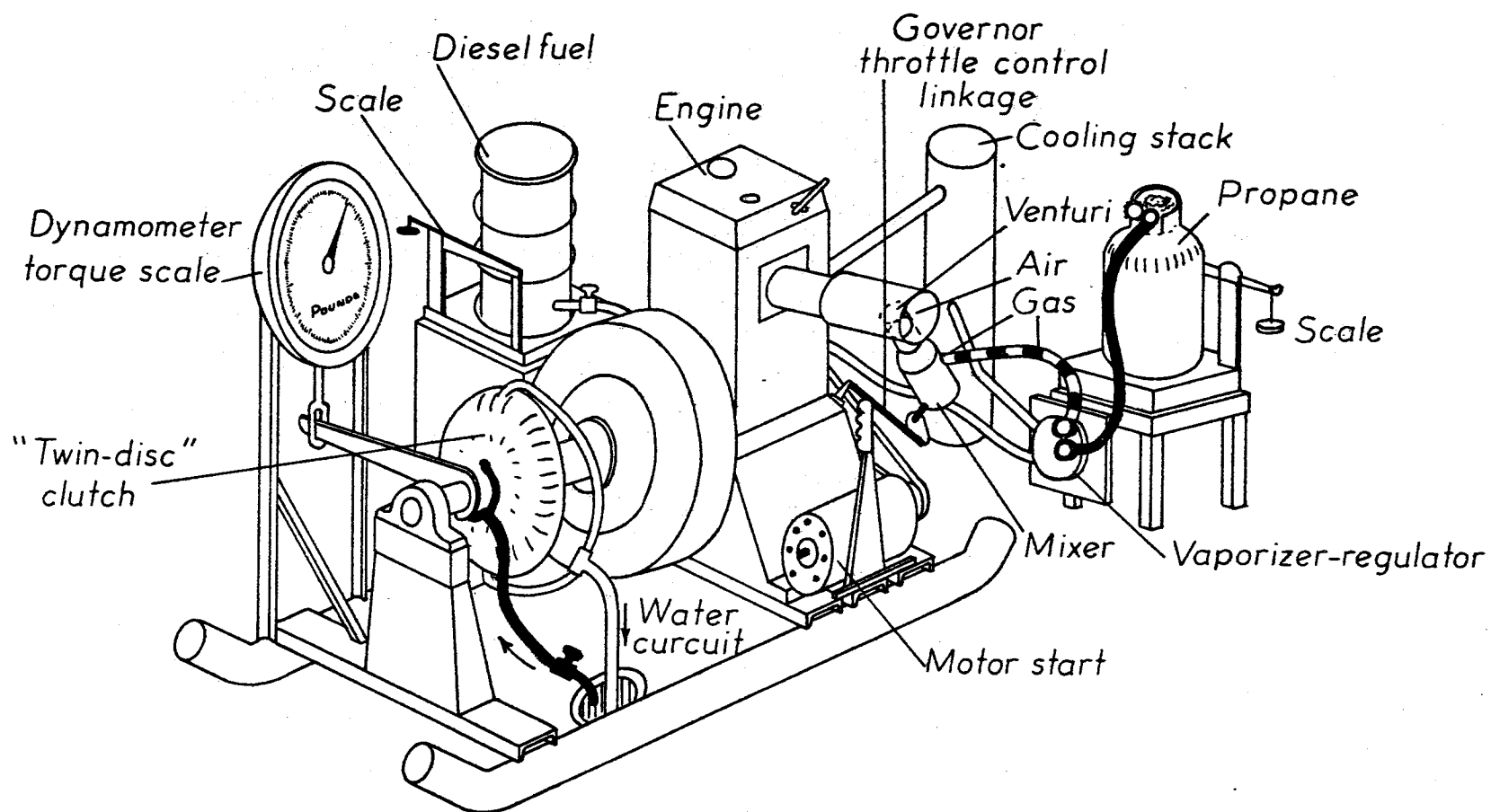


Table II. Comparative Performance Diesel vs. Dual-Fuel  
Wheel Horsepower at 30 m.p.h. (1)

Diesel	55	58
Dual Fuel (RCA) (2)	103	-
Dual Fuel (Commercial) (3)	-	88

- (1) Tests performed on a Mack 4-cycle diesel bus at the Edmonton Transit System dynamometer test stand.  
 (2) Research Council-designed equipment as shown in figure 11.  
 (3) Commercial kit for dual-fuel; Ellis Manifold Corp. 3134E. Washington Blvd., Los Angeles 23.

A similar system is supplied by Beam Products Mfg. Co., 3040 Rosslyn Street, Los Angeles 65.

Table III. Comparative Brake Horsepower - Fairbanks Morse  
Single Cylinder Diesel

10% propane HP	Diesel HP	Speed	
-	6.00	1800	Note: On 10% propane running at 1600 r.p.m. torque advanced by approximately 30% from 4.82 HP to give total HP of 6.25. Conditions: Smokeless up to 5.5 HP; heavy smoke at 6.25 HP. Maximum horsepower of engine not attained at 1800 r.p.m. since information was not available on the strength of component parts and damage to the engine might have resulted. Apparatus: Similar to that shown in figures 11 and 12.
-	5.43	1700	
6.25	4.82	1600	
	4.21	1500	
	3.45	1400	
	2.67	1300	
	2.35	1200	
	2.05	1100	
	1.78	1000	

and smoke characteristics may be optimum at diesel percentages of as low as 10% by weight of fuel. A diagram of the test apparatus appears in figure 12.

F. Tests Performed by Department of Agricultural Engineering. In 1958 Professor F. V. MacHardy<sup>3</sup> did research at Northwestern University on fuel distribution in engine manifolds which showed that propane and butane could be superior to gasoline in this respect. During the course of the investigation it became evident that erratic behaviour in LPG engines was not caused by any improper mixture distribution, but by faulty operation of the vaporizer-regulator, and that lean mixtures could occur very easily under heavy load conditions due to limitations of the mechanisms and designs in use. Since lean mixtures are the cause of a good many mechanical problems including speed instability under load and overheating due to slow burning of the mixture, MacHardy suggested that a closer examination of the vaporizer-regulator be made. Slow burning can cause very high exhaust temperatures which may give valve trouble and ring seizure.

In 1960 Professor B. T. Stephanson completed a study of the influence of gasoline and propane fuels on spark ignition engine wear rates during low temperature operation. Comparative tests performed on wear rates in propane and gasoline operated engines at low temperatures suggested that there is no significant difference in wear between the two types<sup>8</sup>. However, this research brought out several important new facts about cold temperature lubrication, and established the main point that wear is more likely to be caused by oil contamination than by any other factor.

### Conclusions and Recommendations

The seasonal market situation in propane was one of the first considerations leading to automotive research. When it is economical to buy LP gas equipped engines or install conversion equipment in farm engines, the research reported here should provide direction for the prevention of mechanical problems. In other cases, where butane is available at low cost those who wish to use this fuel will find the reported experiments useful. In addition, where operators of 4 stroke-cycle diesel trucks and tractors desire either less smoke or greater power, the methods shown here will provide sufficient information to enable dual-fuel conversion.

In using propane for engines it is important to remember that propane is a premium fuel with an estimated octane rating of from 110 to 130. This means knock-free performance, but it also means that normal danger signs due to engine overheating, which an experienced operator may listen for, are absent. If the fuel mixture is too rich or too lean this may not be as apparent as in a gasoline engine. Butane is closer to gasoline in performance, and may be used at low temperatures as a direct substitute for it in a regular gasoline system, but cannot be used in unmodified conventional LPG conversion kits due to low vapor pressure. Even propane sometimes has insufficient vapor pressure to operate satisfactorily, and extra ethane (or methane) is often added by the suppliers in winter to improve this.

As a result of its physical characteristics, propane has some advantages over other fuels. It mixes easily and completely with air; as shown by MacHardy<sup>3</sup> it reaches all cylinders in an even mixture. This means that the carburetor does not need special high speed jets or the extra mechanical modifications that are necessary when gasoline, a less volatile fluid, is used.

Propane is a clean gaseous fuel and burns almost completely, producing very little carbon monoxide. It is therefore relatively safe for use in warehouse vehicles.

Since propane is clean it also causes less deterioration of lubricating oil, and blow-by of combustion products does not reduce the crankcase oil to an acidic state. Propane engines have a history of long life<sup>2</sup>, low bearing and cylinder wear, and clean oil. In buses and trucks the products of combustion do not have unpleasant odors.

Some disadvantages of propane are its tendency to leak at pipe joints, its inflammability, the investment necessary to keep it contained (high pressure special tanks are required), and its history of burned valves and scored pistons due to improper use.

On the basis of the research reported here, some advice may be given for LP gas automotive systems. When a decision has been made to convert a gasoline engine to propane or butane, it is wise to consider the condition of the engine. If the engine is old, propane especially may not be very efficient. The high octane rating of propane enables its use in an engine of compression ratios<sup>4</sup> as high as 14:1. This means that if the engine one wishes to convert has low compression, a good deal of available power will be wasted. It is analogous to using a higher octane gasoline than necessary. Some authorities consider the diesel engine, stripped of its injectors and supplied with carburetor and ignition system, the ideal engine for conversion. It may be unwise to "shave" the head of a modern gasoline engine to raise the compression ratio without enlarging the main bearings or using a heavy-duty crankshaft. More power is useful, but not at the expense of mechanical failure.

In converting an engine to LP gas it is also wise to consider what effect an increase in compression ratio will have on spark ignition. It may be necessary to obtain a coil producing higher voltage in order to make the spark jump the air gap under higher pressure conditions.

With regard to the conversion equipment itself, there is not much preference in makes or brands, but one should select a vaporizer-regulator of sufficient size, place it low enough always to have engine coolant in it, and if possible keep the engine and engine compartment as near a constant temperature as possible by means of automatic shutters or other thermostatic devices. Walker<sup>9</sup> has also reported the importance of constant temperature in mixture control. He notes that close control of engine temperature will insure that the LP gas will have a reasonable uniformity of temperature, and goes on to explain that this is the best way of proportioning gas volumes accurately, or preventing lean mixtures.



It is considered advisable to have the tank mounted close to the engine and to locate all of the high-pressure lines in a relatively compact area. Vibration has a tendency to loosen connections, and many a potential accident can be eliminated by arranging a compact, simple piping system. The tank should be in a place where it can be vented, should pressure rise sufficiently to open the safety release valve.

Where copper piping and flange connections are made, it is important to consider the effects of vibration in pulling the copper out of the connectors. Preferably, connections should be made of flexible high pressure hose, and be kept as short as possible. Leaks are an ever-present problem.

In the author's experience a vapor withdrawal system is preferable to liquid withdrawal. A temperature control on the tank may be used to regulate internal pressure. Where liquid withdrawal systems are in use, fuel filters are necessary to prevent build-up of heavy solubles on sensitive diaphragm mechanisms.

If butane is to be used in vehicles, conventional LP gas equipment is satisfactory with the addition of a simple water heating system to warm the tank sufficiently to give operating vapor pressure. In cold weather it is advisable to use a dual-fuel (gasoline and butane) system, since it may take some time for the engine to become warm enough to give heat to the butane tank. The upper limit of vapor pressure produced by a tank full of butane at 180°F. is 172 pounds per square inch. (Propane reaches 272 pounds per square inch at 130°F., sufficient to open the safety valve, so that if the same tank is used for both fuels, a 100° thermostatic bypass is suggested). Adequate pressure for running on vapor withdrawal will require some experimentation, but anything above 25 p.s.i. was found satisfactory for operation of a 150 HP engine. Another technique, that of using a submerged fuel pump in the pressure tank, has many possibilities. This has been tried for highly volatile gasolines with some success<sup>11</sup>.

For dual-fuel operations, that is, to use propane in a diesel engine, the commercially available conversion kits are considered satisfactory. However, these kits are primarily "topping" or high load units which operate on 3/4 throttle and over. Simonson<sup>6</sup> has reported a lowering of fuel economy when the dual-fuel engine assumes part-load conditions, and recommends a return to straight diesel for I.M.E.P. of less than 100 p.s.i., or 3/4 throttle setting. This would indicate that the "topping" technique is practical. However the relative fuel costs will be the deciding factor in over-all dollar economy, and the apparatus described in experimental work (figure 11) is recommended for engine flexibility. It will be necessary to have long-term experimental field results, however, before it can be stated positively that side effects such as sludge formation, hot spots in the engine, hot exhaust, etc. are not to cause trouble. Some operators claim a mixture of the two fuels is dangerous since diesel engines have not been designed to stand abrupt changes of speed. Perhaps the outcome of this research will be the designing of new and more efficient dual-fuel engines. The theoretical possibility of reaching a thermal efficiency approaching 40% is worth a considerable effort.

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