THE PERFORMANCE OF LIQUEFIED PETROLEUM GAS CARBURETORS

by

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INTRODUCTION

LP Gas, an abbreviated term for liquefied petroleum gas, is coming into expanded use in internal combustion engines. In the past this fuel has been wasted by venting it into the atmosphere as a vapor and burning it during the process of producing natural gas and refining crude oil. This process was practiced because there was no demand for these particular fractions of the natural gas or crude oil which justified the expense and the effort necessary to save the vapors. In order to conserve our natural resources, laws, which prohibit this wasteful practice of flaring, have been passed in recent years by congress.

These vapors are now saved by forcing them into containers or bottles which keep them in the liquid state under moderate pressures. The containers are distributed to consumers beyond the natural gas mains where the fuel is used for the heating of the home, the heating of water, and for cooking just as natural gas is used. In addition to these uses, LP Gas has been accepted as a motor fuel which has been found to be of superior quality to the best gasoline.

At our present rate of petroleum consumption our petroleum supply could be depleted very seriously in the event of a major war. Our agricultural machines and vital transportation vehicles must continue in operation regardless of the state of national affairs. The large-scale utilization of LP Gas as a motor fuel could lessen the demand for gasoline and other petroleum fuels by an amount sufficient to allow a greater maximum use of our petroleum in either war or peace.

Ever since the first engine was built, the automotive engine manufacturer and designer has been plagued by a demand from the public for an engine that could utilize many different fuels. The designer has been called upon to build external combustion engines which could use coal, wood, and other solid fuels; and internal combustion engines for such fuels as gasoline, kerosene, distillate, and Diesel fuel. And now a new fuel has been added to this list. Within the past five years a demand has been made for engines which will utilize the LP Gases, and this demand is steadily growing.

Alden and Selim (1) have reported sales of 25,300 conversion units during 1949. These figures do not include all units sold, but only those reported to Alden and Selim in their survey. Alden and Selim also predicted that the sale of conversion units during 1950 would exceed 100,000 and would exceed 170,000 by the end of 1951.

A careful survey made by the Butane-Propane News (6) shows that there are now 87,320 converted tractors in the United States. The two states with the largest number are Texas and Kansas with 18,190 and 14,390, respectively. The other states range from 100 to 5,000 converted tractors each.

The demand for engines which will use many different fuels comes to the designer and manufacturer because the operator, whoever he may be, wants to use the cheapest fuel available. The designer is then faced with additional complex problems when the operator wants to use one fuel until it becomes too high in price or too hard to obtain. He than wants to be able to switch to another kind of fuel without stopping except to refill the fuel tank or to make a simple adjustment of the fuel-feeding mechanism.

The principal reason that the present demand is being made for LP Gas as a motor fuel is that it is a cheaper fuel than gasoline, which is the most common tractor, truck, and automobile fuel used today. The price of LP Gas is directly dependent upon the distance necessary to transport the fuel, therefore the price will vary a great deal in different sections of the United States. In those sections where the price is too high there is very little demand for the fuel. In sections where the price is sufficiently lower than gasoline the demand is greater. Table 1 shows how the demand is distributed over the United States (1).

Table 1. Sales distribution of LP Gas conversion units over the United States.

Territory	1948	1949	% Territory sales
East coast	1,000	2,300	6.2
East central	1,200	1,700	4.5
West central	4,600	10,000	26.9
South west	10,000	14,100	37.9
South east	900	4,400	11.8
Mountain	3,100	3,900	10.5
West coast	4,500	800	2.2
Total	25,300	37,200	100.0

The LP Gases are a very important element in our national motor fuel problem. Less complex regulation equipment with greater efficiency will undoubtedly appear in the near future. All information of a technical nature will be of value to the designer of this equipment. A broad knowledge of the characteristics of the LP Gases should be obtained by any person who handles or uses the fuel. This would be a good safety promoter and would increase the effectiveness with which the fuel could be used.

OBJECTIVES OF THE INVESTIGATION

The objectives of the investigation were:

1. To compare the performance of the pressure injection carburetor with the conventional carburetors as to:
    - a. Maximum power developed
    - b. Fuel consumption
    - c. Ease of starting
    - d. Ease of adjustment
    - e. Ease of adapting to engine
2. To determine the effect of the fuel vapor temperature on:
    - a. Fuel consumption
    - b. Air-fuel ratio

REVIEW OF THE LITERATURE

Fuel Injection

There has been a considerable amount of research work done on the injection of gasoline and other liquid fuels in spark-ignited engines. The fuel is injected by a nozzle which mechanically vaporizes the fuel and mixes it with air. There are two types of fuel injection engines, the "port or manifold" type, and the "direct or cylinder" type.

Brook and Nicolls (5) have given the following definition for a fuel injection engine:

> The term fuel injection engine is used to describe the method of supplying fuel to an internal combustion engine whereby air only is drawn in through the intake manifold during the suction stroke and a metered amount of fuel is sprayed (in atomized form) into the cylinder and this mixture subsequently is compressed and ignited by a spark.
>
> The fuel injection engine, therefore, differs from the carbureted engine only in the way in which the fuel is added to and mixed with the intake air. The fuel injection engine should not be confused with the compression ignition engine in which the fuel is injected very near the end of the compression stroke and is ignited by the heat of the highly-compressed air.

The early (1938) experiments of Brook and Nicolls were run on a single cylinder taken from a nine cylinder aircraft engine. It was a two stroke cycle engine because the aircraft designers wanted to obtain the maximum power output per unit of weight. They used Diesel injection equipment with gasoline as the fuel.

The viscosity of gasoline is less than Diesel fuel. Therefore, considerable trouble was encountered by seizure of the plunger by the barrel walls. Lubrication was added to the fuel, but was not favorably effective in remedying the trouble. They cut grooves in the side of the plunger which did not aid in completely lubricating the surface, but it proved to be more effective than when only a lubricant was added to the fuel.

Trouble was also experienced with leakage past the plunger, and in delivering the correct amount of fuel. The manufacturing and development of injectors have advanced by a large degree since these tests were made; however, Brook and Nicolls spent much of their time and finances in the development of injection nozzles and pumps, and their tolerances were as accurate as any manufactured today.

Brook and Nicolls' results showed that with the injection of liquid gasoline in a fine spray at the intake valve port, the performance of the single cylinder engine was at its best.

Lange and Van Overbeke (10) ran tests on a four cylinder Minneapolis-Moline tractor engine with distillate as fuel. They reported that with the carburetor in operation, knocking became apparent at a compression ratio of 4.3:1. After converting the tractor to a fuel injection engine, using the port injection nozzle, the compression ratio was increased to 4.8:1 before the same degree of knocking became apparent.

Lange and Van Overbeke also ran a Hercules engine with the carburetor in place, with the fuel being fed by port injector nozzles. They reported a slight increase in power output and a slight reduction in specific fuel consumption. They then removed the intake system and installed individual intake pipes. With the same injection nozzles placed at the intake ports they reported a great increase in power output with a slightly greater reduction in specific fuel consumption.

Taylor, Taylor, and Williams (19) ran similar tests with fuel injection engines. A Diesel-type injection pump was used. The Diesel nozzle was used for injection into the manifold and a specially-designed nozzle was used for injection directly into the cylinder. A series of tests were run to compare the performance of an engine having (a) injection into the inlet pipe and (b) injection into the cylinder. These tests were compared with the performance obtained with the conventional carburetor. Fuel injection into the inlet pipe or cylinder was found to be superior in performance to the usual type of carburetor. The available power was increased by over ten percent with injection into the cylinder, and seven percent with injection into the intake pipe. The direct and manifold injection gave substantially lower fuel consumption.

The mechanical problems of injection were found to be simpler than for compression ignition operation. E. S. Taylor reported that the influence of fuel injection on the compression ratio which could be used was not very significant, but that the compression ratio could be raised slightly. C. F. Taylor made the statement that no trouble should be experienced with injection equipment for spark-ignited engines because injection timing is less exacting than the Diesel. He also says:

> However, with gasoline injection it is important that lubrication be provided for the pump plunger and that close fits be avoided at sliding surfaces in injection valves. Otherwise, binding and wear will result in the ultimate failure of the parts.

Wiegand and Meador (22) have done a considerable amount of research on fuel injection in aircraft engines. The fuel injection engine has more advantages in aircraft than in automobile engines as will be pointed out.

Wiegand and Meador ran tests on a nine cylinder aircraft engine connected to a dynamometer. They reported that with the port fuel injection system the thermal efficiency of the engine was increased by two percent throughout its useful load range over the efficiency when the carburetor was used. The average cylinder head temperature was twenty degrees Fahrenheit less with the injection system than it was with the carburetor. They took individual exhaust samples from each cylinder and found the air-fuel ratio to be much more uniform than with the carburetor. The engine ran with less vibration in the lower range of its power.

Wiegand and Meador also operated a nine cylinder engine mounted in an aircraft, equipped with an injection system, on kerosene. In order to start the engine, gasoline had to be utilized. However, just as soon as each cylinder had fired once the kerosene could be turned on. The airplane was never tested in flight, but seemed to develop ample power for take-off before detonation was too severe.

They summarized their results thus:

1. Injection into the cylinder is preferable to manifold injection because fuels of lower volatility can be used.

2. The position of the nozzle when using the direct type was very critical because the lower volatile fuels would condense on the cylinder walls and pass into the crankcase.

3. The duration of injection time was not critical.

4. In a highly supercharged engine the fuel should be vaporized ahead of the compressor because the resulting lowering of the air temperature increases the density of the air and improves the compressor performance. The vaporization of the fuel cools the air about forty degrees Fahrenheit.

5. Serious backfires in the intake system during cranking were eliminated.

6. Icing of the carburetor was eliminated.

7. When the engine once started, it kept running.

The Ex-Cell-O Corporation (7) states that the fuel injection system on aircraft engines eliminates the danger of carburetor icing entirely. They also report that the maximum cylinder head temperature can be substantially reduced, and that improvement in power and acceleration performance was noted by the pilots. A reduction in the fuel consumption was evident as was the improved performance of the plane in maneuvers. Positive control of the air-fuel ratio is possible according to the altitude.

Voltz, Smith, and Balis (21) state that the delicacy and complexity of the fuel injection engine will necessitate a higher first cost. The repair and maintenance will require a person skilled and experienced in this particular field. Therefore, the fuel injection engine, even though it presents the superior performance, will be suited only for the luxury class.

Jamison and Strather (9) have made the following statement concerning the prospects of pressure injection of LP Gas:

> Because propane and butane vaporize so readily, their use would make fuel nozzle design far less critical. Nozzles would be much less inclined to clog because these fuels deposit surprisingly little carbon. These views are mere hypotheses since they have not been put to test, but they are served up as food for thought.

The Barnes and Reinecke Corporation (2) has developed a system for multi-fuel injection which is described by the following paragraph:

> The injection system of the Barnes and Reinecke engine is capable of successfully injecting a range of fuels from ordinary Diesel fuel to high octane aviation gasoline and propane without inducing knocking combustion. Change over from one fuel to another is accomplished by a single control on the engine adjusting the timing of the injection pump to the octane number of the fuel injected. This control works entirely through the injection pump. Development of the multi-fuel feature was concentrated in the injection pump only and can therefore be used on any existing Diesel engine by simply exchanging the injection pumps. It was found that successful injection becomes progressively difficult as the octane number of the fuel increases with a consequent decrease in cetane number. Considerable development was correspondingly necessary to achieve smooth engine operation with fuel of 100 octane and higher. Development centered on cam shape, fuel supply system, and suction and discharge valves of the injection pump.

Before this investigation was begun, an effort was made to investigate the possibility of metering the LP Gases directly into the cylinder as is being done with gasoline.

However, it was felt that all of the problems mentioned by Brook and Nicolls and C. F. Taylor would be encountered and that an investigation of that type would be beyond the scope of this study.

It is true that the Barnes and Reinecke Corporation has been able to use propane in Diesel equipment as was just mentioned. However, no results have been published regarding the durability of nozzles and pumps or how lubrication for the parts was provided.

To the author's knowledge the Garretson pressure injection system is the only unit that is in public use today which forces the LP Gas fuel into the intake air. Therefore, an investigation of the characteristics of this system as compared to the conventional carburetor was thought to be an asset to the industry.

Fuel Temperature

To the knowledge of the writer no work has been published on what effect changes in fuel vapor temperature of LP Gas has on carburetion characteristics. This is an important aspect in LP Gas carburetion because heat is added to the fuel in order to vaporize it. The amount of heat added may vary on different engines operating under varying conditions.

Browne (4) has shown the effects of temperature on liquid gasoline and makes the following statement:

> The property of viscosity is not ordinarily associated with liquids as light as gasoline. It is a fact, however, that the flow of gasoline through the nozzle of a carburetor is directly affected by changes of temperature.

Browne shows by an illustrated chart the flow of liquid gasoline at temperatures between fifty degrees Fahrenheit and one hundred degrees Fahrenheit. At one hundred degrees Fahrenheit the flow discharge by the nozzle was thirty-six percent greater than the flow at fifty degrees.

Browne makes the following comment on the results shown in the chart:

> It is thus seen that a carburetor nozzle adjusted to give a proper mixture at a working temperature of one hundred degrees Fahrenheit will discharge, but a little over seventy-one percent of requisite fuel when the temperature falls to fifty degrees Fahrenheit, which as has been shown, is the very time when an excess of fuel is needed.

DESCRIPTION OF THE LP GASES

LP Gases, consisting largely of propane and butane, are hydrocarbons with the chemical formulas C_3H_8 and C_4H_{10}, respectively. The principal source of the LP Gases are the by-products from natural gas wells and from refineries processing the crude oil. The natural gas coming from the wells is under a very high pressure ranging from five hundred to one thousand pounds per square inch or higher. All but the most volatile components of the gas will be condensed and will be in a "wet" state at this pressure. The heavier components, propane, butane, and heavier hydrocarbons of this very volatile natural gas are absorbed from the natural gas near the well site because they are in the "wet" state. The natural gas is then piped to towns and cities for consumption, and the propane and butane are forced into pressure vessels under sufficient pressure to keep them in the liquid state.

At the refineries where the crude oil is processed, the lighter components of the crude oil are the butane and propane.

The remainder of the crude oil is made up of gasoline of different grades, kerosene, Diesel fuel, and lubricants. As the crude oil is heated at the outset of the refining process, the first vapors to come off are the more volatile butane and propane components. These vapors are then cooled and forced into pressure vessels just as they are at the natural gas wells.

When the propane or butane fuels are in their gaseous state, their characteristics are very similar to natural gas. When they are in the liquid state, they are very similar to gasoline except that they must be contained in a closed vessel capable of withstanding the high vapor pressure.

Table 2 gives the physical properties of pure butane and propane (8). It is interesting to note the difference in vapor pressure of these two fuels at one hundred degrees Fahrenheit and the difference in temperature at which they would tend to stay in the liquid state at atmospheric pressure.

Table 2. Physical properties of two LP Gases.

Properties	Propane	Butane
Formula	C_3H_8	C_4H_{10}
Vapor pressure at 100° F.		
Lbs. per sq. in gauge	174.8	37.3
Lbs. per sq. in absolute	189.5	52.0
Normal state at atmospheric pressure and 60° F.	Gas	Gas
Boiling point of liquid at atmospheric pressure		
°F.	-43.8	31.1
°C.	-42.1	-0.5

Table 2. (cont.).

Properties	Propane	Butane
Weight of liquid @ 60° F.		
Pounds per gallon	4.23	4.86
Specific gravity	.508	.584
API gravity	147.0	110.0
Cubic feet of vapor at atmospheric pressure and 60° F. formed from		
1 gallon of liquid @ 60° F.	36.45	31.79
1 pound of liquid	8.62	6.54
Weight of vapor at atmospheric pressure and 60° F.		
Pounds per 100 cu. ft.	11.62	15.31
Specific gravity (Air = 1)	1.522	2.006
Gross heat of combustion		
Btu per pound	21,690	21,340
Btu per cu. ft. @ 60° F.	2,521	3,267
Btu per gallon @ 60° F.	91,300	103,000
Cubic feet of air to burn 1 cu. ft. of gas at atmospheric pressure and 60° F.	23.87	31.03
pounds of air to burn 1 pound of gas.	15.71	15.49
Explosive limits		
Lower percent of air	2.0 - 2.4	1.5 - 1.9
Upper percent of air	7.0 - 9.5	5.7 - 8.5
Heat required to vaporize liquid at the boiling point and atmospheric pressure		
Btu per pound	183	166
Btu per gallon	774	797
Ratio of liquid volume @ 60° F. to gas volume @ atmospheric pressure and 60° F.	272.7	237.8

Table 2. (concl.).

Properties	Propane	Butane
Freezing point of liquid at atmospheric pressure		
°F.	-305.9	-216.9
°C.	-187.7	-138.3
Molecular weight	44.094	58.12
Gallons per lb. mol at 60° F.	10.41	11.94
Specific heat at atmospheric pressure @ 60° F.		
C_p liquid - Btu per lb. per °F.	——	.55 @ 32°F.
C_p vapor - Btu per lb. per °F.	0.390	0.396
C_v vapor - Btu per lb. per °F.	0.346	0.363
C_v vapor - Btu per lb. per °F.	1.128	1.090
Critical conditions		
Temperature °F.	206.2	305.6
Temperature °C.	91.4	152.0
Pressure - atmospheres	42.0	37.5
Density - lbs. per gallon	1.888	1.891
Volume cu. feet per lb. mol	3.990	4.130
Pressure - lbs. per sq. in. abs.	617	551

In Table 3 the properties of LP Gas are compared with other common motor fuels (23). It is interesting to note the comparative octane rating and Btu per pound and per gallon of the various fuels.

Table 3. Comparison of properties of motor fuels.

Fuel	#/gal.	Btu/#	Btu/gal.	Octane number
Propane	4.25	21,680	92,300	120
Butane	4.80	21,300	102,500	100
Premium gasoline	6.06	20,320	123,200	80

Table 3. (concl.).

Fuel	#/gal.	Btu/#	Btu/gal.	Octane number
Regular gasoline	6.13	20,280	124,300	72
Kerosene	6.76	19,830	134,100	10
Power fuel	6.50	20,020	130,000	45
Distillate	6.88	19,750	135,800	30
Diesel fuel	7.08	19,590	138,800	55 Cetane

The fuel used in the tests of this investigation was commercial propane. The specifications of this fuel according to the Warren Petroleum Company (13) are as follows:

Composition of product	
Percent ethane	2.50
Percent propane	96.00
Percent isobutane	1.50
Specific gravity of liquid (60°/60° F.)	0.507
Weight per gal. of liquid at 60° F., lbs.	4.23
Specific heat of gas, Btu/lb./°F. at 60° F. (C_p)	0.391
Total heating value (after vaporization)	
Btu per cu. ft.	2510
Btu per lb.	21,796
Btu per gal.	91,735

The safety with which the LP Gases can be handled as compared to other fuels is a question which comes from many people who are introduced to LP Gas for the first time.

The Butane-Propane Handbook (8) gives the following list of characteristics that should be understood, for the purpose of safety, by a person handling the fuel:

1. The gas or vapor is heavier than air.

2. The vapor or gas will diffuse into the atmosphere very slowly unless the wind velocity is high.

3. Open flames will ignite air-gas mixtures which are within the lower and upper flammable limits.

4. Gas-air mixtures may be brought below the flammable limit by mixing with large volumes of inert gases such as nitrogen, carbon dioxide, or steam.

5. Fine water sprays reduce the possibilities of igniting gas-air mixtures.

6. The vapor pressure of this fuel is greater than that of gasoline. It is safely stored only in closed pressure vessels built according to regulations and equipped with safety devices as required.

7. Liquids in open vessels will evaporate to form combustible mixtures with air even if the atmospheric temperature is many degrees below the boiling point.

8. The rapid removal of vapor from the tank will lower the liquid temperature and reduce the tank pressure. The rapid removal of liquid will not reduce the tank pressure.

9. The liquids will expand in the storage tank when atmospheric temperature rises. Storage tanks must never be filled completely with liquid.

10. Liquid obtained from the storage tank will freeze the hands on contact, even if gloves are worn. This is due to the rapid absorption of heat by the liquid on vaporization in the open.

11. Condensation will occur in gas distribution lines when surrounding temperatures are below the boiling point of the liquid.

12. The liquefied petroleum gases are excellent solvents of petroleum products and rubber products. Special pipe joint compound and rubber substitutes are available for use in distribution systems.

The Butane-Propane Handbook also states:

> LP Gas is not poisonous. The breathing of small concentrations for short periods will produce no noticeable effect on the human being. Exposure to higher concentrations for short periods, while undesirable, is not dangerous to life.
>
> The records show that LP Gas is handled safely year in and year out when its properties are understood and proper precautions are observed in its handling and in the design, construction, and installation of the various appliances and equipment necessary to its use.
>
> In checking its comparative rating as a fire hazard, it is interesting to note that electricity, because of defective wiring, leads the list as the chief cause of fires. Oil comes next, the fires being caused by failure of regulating equipment, by leaks in the lines, by spillage, and by explosions. Wood is third, and coal is fourth. Last on the list is gas, considered by many fire preventive organizations as the safest fuel.

When the LP Gases were first used as engine fuels, no great effort was made to utilize them to their highest efficiency. Butane was preferred to propane because of its lower vapor pressure which made regulation and carburetion equipment less critical and because butance which contains more heat units per gallon than propane made it a little cheaper. Butane has proved to be a valuable raw material in the manufacture of synthetic rubber, and a considerable quantity is mixed with premium gasoline. These uses make the availability of butane at a low price uncertain.

However, there has been no good use developed for propane except as a fuel for heating or internal combustion engines. The trend today is for the use of straight commercial propane in internal combustion engines. The potential availability of propane is apparently far in excess of any foreseeable demand. Because of the laws preventing flaring, the oil and gas producers must now find a use for the LP Gas or put it back in the ground. Some progress has been made toward the possibility of storing the commercial propane in man-made reservoirs underground (14).

A. T. Browne (3) shows the total sales of LP Gases to be a little in excess of three billion gallons in 1948. About one-half of this amount, or 1,500,000,000 gallons, was propane and about one-tenth of the propane, or 150,000,000 gallons, was used as a motor fuel. He shows the potential production of LP Gas to be in excess of 16,000,000,000 gallons of which propane makes 10,500,000,000 gallons. These figures indicate we are using only 1.44 percent of the available propane as a motor fuel.

It is seen by this that the use of propane as a motor fuel can be greatly expanded. The fuel has to be produced if other petroleum products are, as it is a by-product of them, and it is a forbidden practice to waste the fuel. Therefore, it can reasonably be expected that the use of propane as a motor fuel will increase because the producer on one side is endeavoring to develop a market whereas the tractor, truck, and bus operators on the other side are seeking the most economical means of operation.

Propane has proved itself to be an excellent internal combustion engine fuel. It has some disadvantages when compared to gasoline or Diesel fuel in that it has less heat units per gallon. However, this disadvantage is true only because the fuels are sold by the gallon, and one gets less Btu's per unit of money. The heat content of a fuel in Btu's per gallon is no indication of the power producing ability of that fuel. The heat content, in Btu's per cubic foot, of an air-fuel mixture is the direct measurement of power producing ability. Lichty (12) gives the Btu content of a chemically correct gasoline-air mixture to be 100 Btu per cubic foot, and the Btu content of a chemically correct propane-air mixture to be 98 Btu per cubic foot. Therefore, the power producing ability of gasoline and propane are virtually the same. The propane has one great advantage over other motor fuels because of its high anti-knock characteristics. The octane rating is given in Table 3 as 120. With this high octane rating the compression ratio of an engine can be increased to the maximum allowable mechanical structure of the engine. The engine will then be much more efficient and will deliver more power. It has been found, however, that when engines are converted to utilize LP Gas that the power output is less, generally in the range of ten percent. This may seem to be a contradiction to what has been stated. However, there are at least two reasons for this loss. First, the engine is converted, but no change is made in the compression ratio to utilize the fuel to the maximum efficiency. Second, the intake manifold being used for gasoline, or a lower volatile fuel, will not let as much propane-air mixture pass through it as it will a gasoline-air mixture and usually the venturi area is reduced by inserting the LP Gas fuel nozzle. When a higher compression ratio is used and a cold manifold is employed on a converted engine, the power output can be increased to equal or surpass gasoline performance.

There are a few engines in use today that have been designed especially for propane fuel. Those engines are developing a higher specific output (horsepower per cubic inch displacement) than could ever be achieved with gasoline.

DESCRIPTION OF CARBURETION EQUIPMENT

There are two methods of feeding LP Gas to the carburetor of the engine. They are the vapor withdrawal method and the liquid withdrawal method. The vapor withdrawal method will be considered first. Figure 1 is a schematic diagram of the vapor withdrawal method.

The fuel tank used with this method is usually of the "bottled gas" type. When mounted on tractors, it has the general shape shown here. The fuel tank can be mounted in the front or to the side of the tractor with the original fuel tank and carburetor remaining in place. An engine equipped with this setup can operate on either gasoline or propane fuel simply by closing one valve and opening another.

The volume in the tank above the liquid is filled with the fuel vapor. The fuel vapor will produce a pressure of 30 to 200 pounds per square inch depending upon the fuel and the surrounding atmospheric temperature. The high pressure regulator provides a constant vapor pressure for the fuel controller. The pressure provided can be set for any amount between 5 and 20 pounds per square inch, depending upon the size of the engine.

The liquid withdrawal method is very similar to the vapor method. Figure 2 is a schematic diagram of the liquid withdrawal

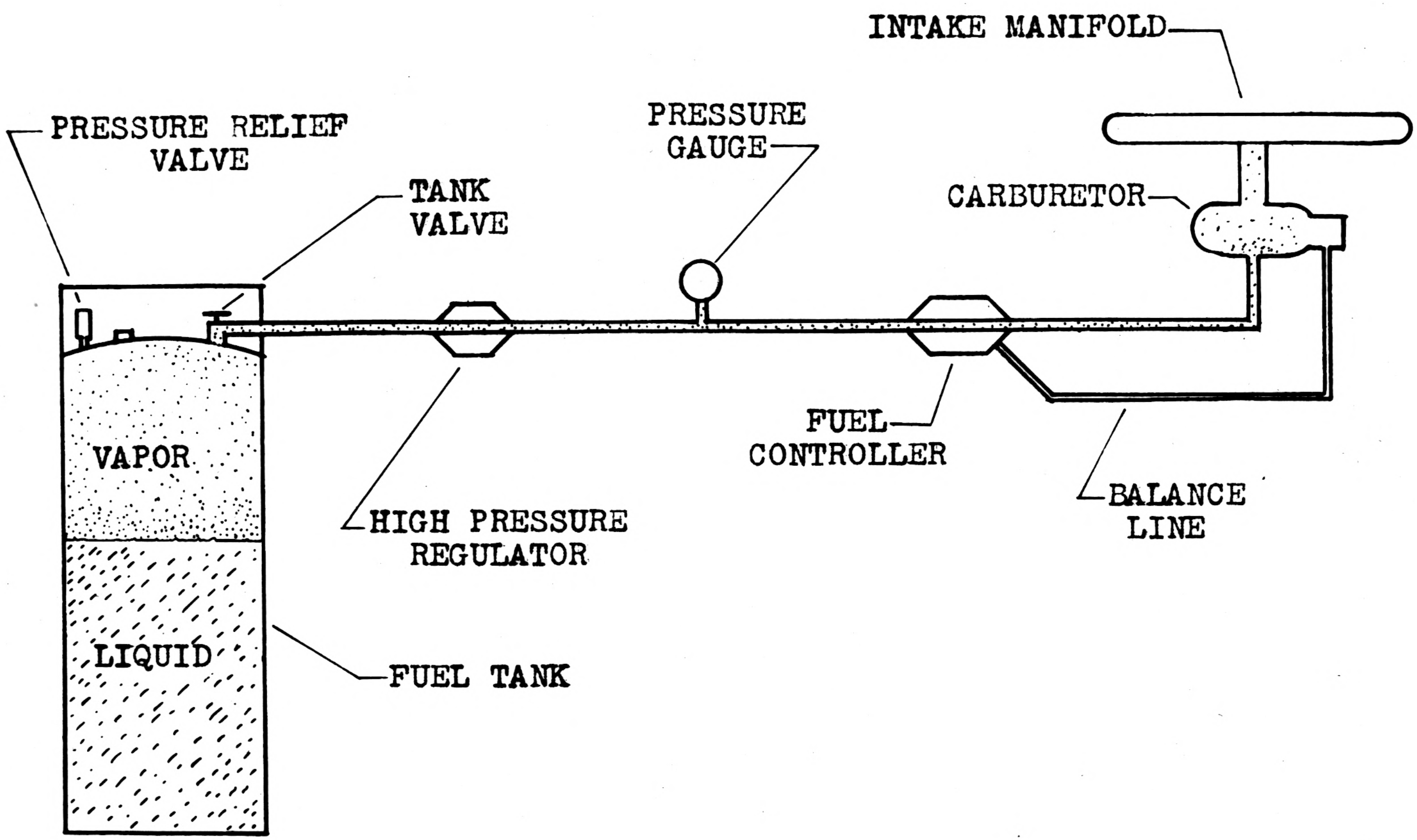

Fig. 1. Vapor withdrawal method (11).

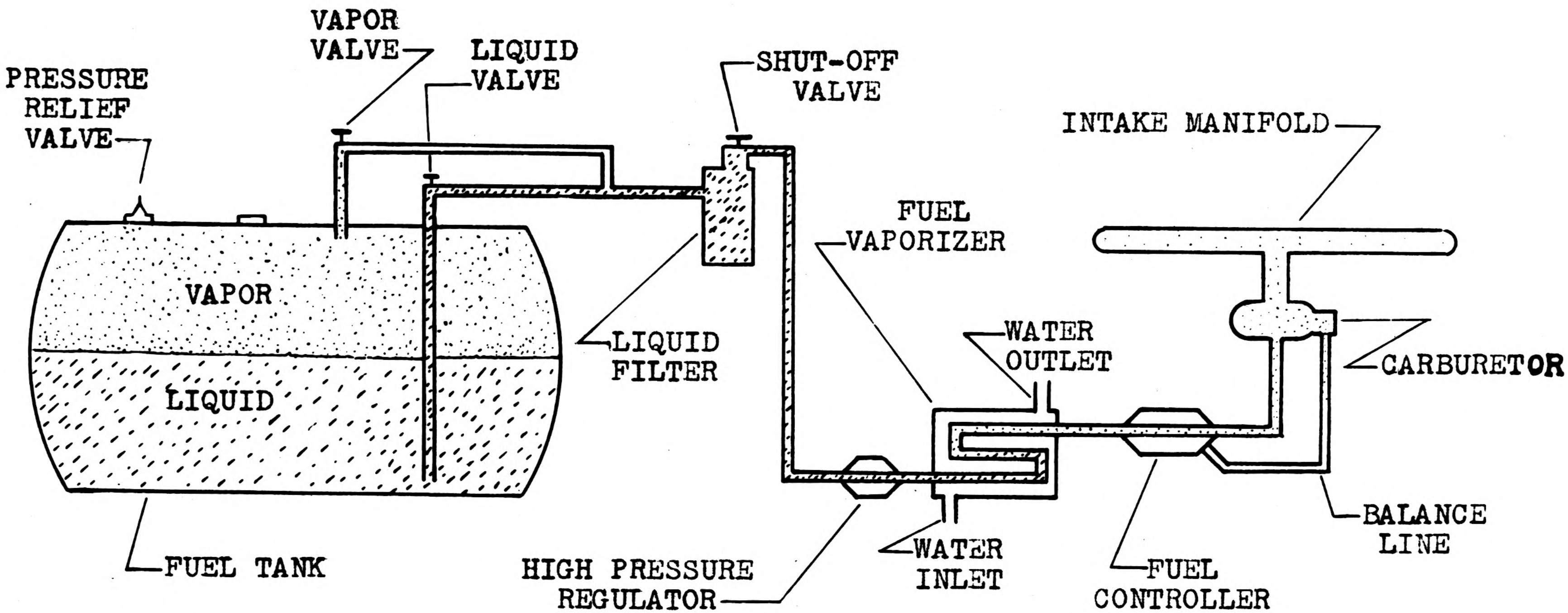

Fig. 2. Liquid withdrawal method (11).

method.

In this method a tube is extended to very near the bottom of the tank. The vapor pressure above the liquid will force the liquid up the tube and through the high pressure regulator. The pressure reduction or throttling process allows expansion and vaporization of the liquid. Under these conditions rapid refrigeration will take place causing serious frosting to occur at the point of throttling. Therefore, the vaporizer unit is included in the liquid withdrawal setup. The vaporizer unit is made up of tubes conducting hot water from the engine over which the fuel passes. Some of the heat in the hot water will pass into the fuel furnishing the heat required for vaporization of the fuel. A typical vaporizer unit is shown by the schematic diagram in Figure 3. After the fuel has passed through the vaporizer the liquid system is exactly like the vapor system.

It is important to note that each of the two systems is designed to feed the propane fuel to the carburetor in the same condition.

The vapor system is the cheaper of the two systems because no vaporizer is employed. It is being used on many tractors, but is limited to small power output. The heat from the atmosphere furnishes the heat required for the vaporization of the fuel. Therefore, the rate with which the vapor can be removed is limited to the amount of heat that can be transfered from the atmosphere into the liquid within the bottle. By referring to statement No. 8 on page 17 it can be seen that with a high power output

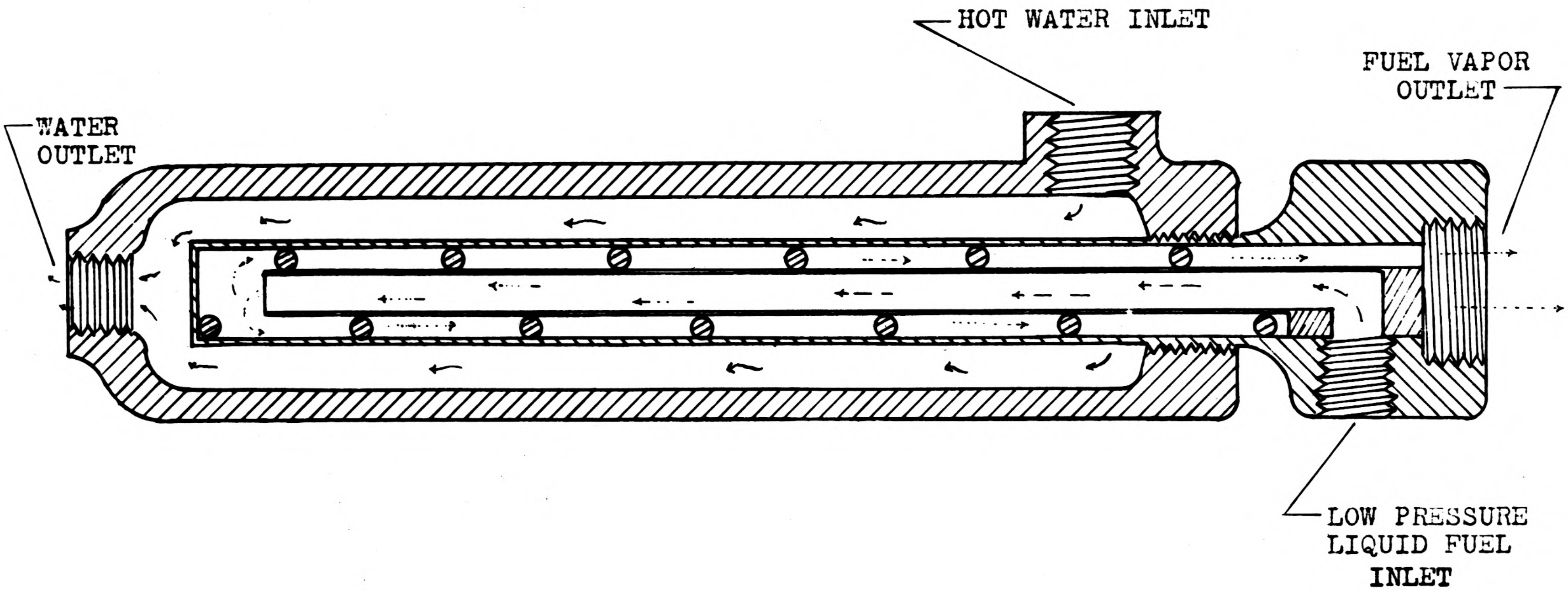

Fig. 3. Fuel vaporizer unit.

and consequently high fuel consumption rate, the pressure and temperature within the tank will be rapidly lowered. If this is continued the pressure will drop too low to operate the engine. There can be no definite horsepower limit stated for the vapor system because of the variable atmospheric temperature. The higher the temperature the higher the power output can be, and vice versa.

It should also be noted here that the type of fuel used has a direct bearing upon the type of system to be used. Butane cannot be used in the vapor system because of its very low vapor pressure (Table 2, page 15). Propane can be used effectively in the vapor system because of its high vapor pressure if the atmospheric temperature is high enough and if the vapor withdrawal rate is not too great.

Figure 4 is a schematic diagram of a high pressure regulator. The fuel, under high pressure, enters the inlet side of the regulator and expands past the pressure throttling valave and fills the space below the diaphragm. If no fuel is removed from the outlet side, the pressure will build up under the diaphragm causing it to move upward against the spring pressure. The linkage mechanism controlled by the diaphragm will close the throttling valve until the fuel is released through the outlet. On the other hand, if the fuel is rapidly removed through the outlet, the pressure will not build up. Therefore, the diaphragm holds the throttle valve in such a position that a relatively constant pressure is provided through the fuel outlet.

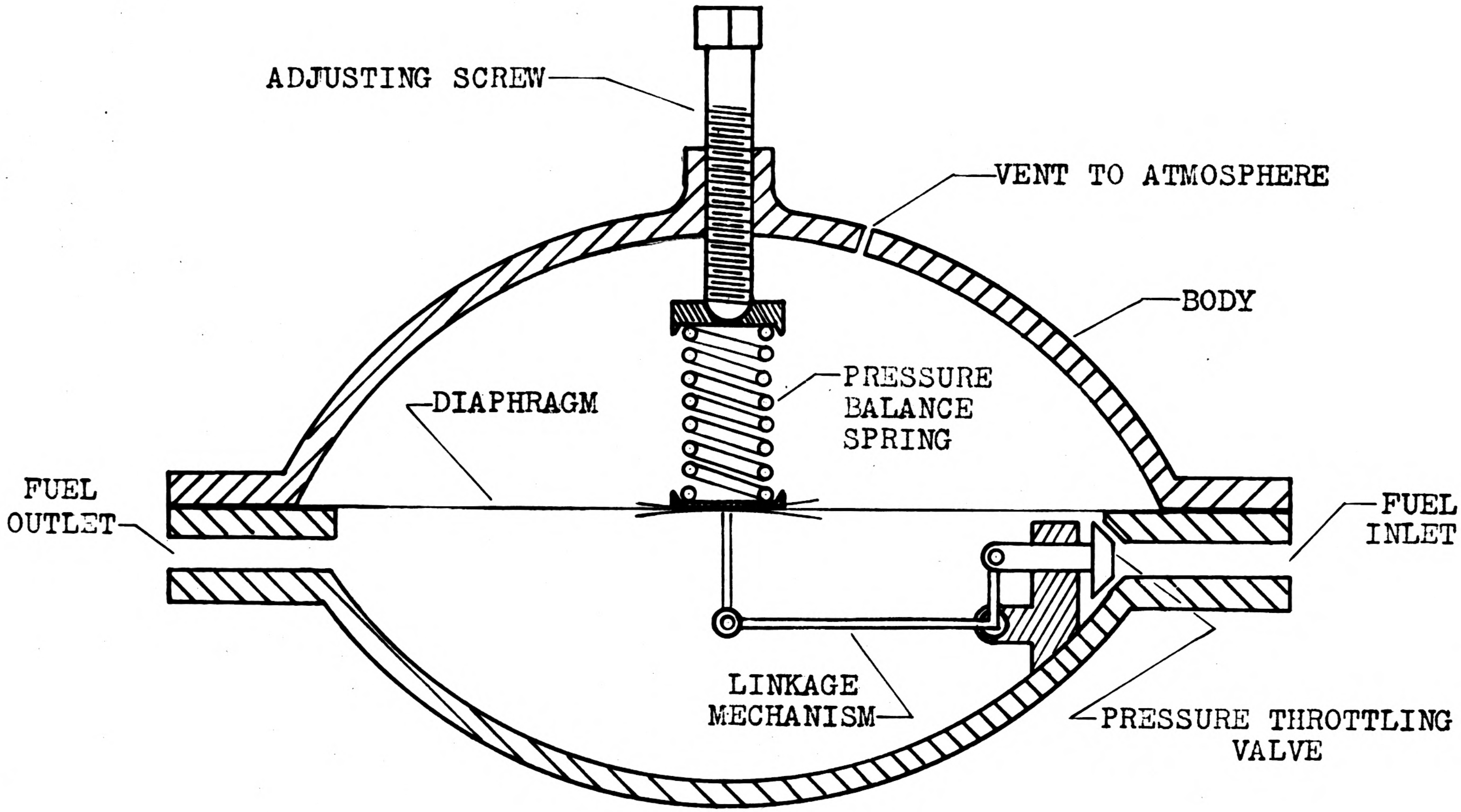

Fig. 4. High pressure regulator.

The regulator will control liquid fuel as well as vapor. Therefore, the same regulator may be used on either method of fuel withdrawal. However, when the regulator is used to control liquid flow, the regulator must receive heat at the throttling valve in order to prevent serious frosting[1] at this point.

For this reason the regulator must be located near the hot water vaporizer. The fuel passes through the vaporizer unit where it is completely vaporized and the temperature of the fuel vapor is raised by the hot water. The temperature of the fuel vapor is dependent upon the water temperature, water flow rate, and fuel flow rate. However, the pressure of the fuel supplied to the fuel controller is constant.

Figure 5 is a schematic diagram of a fuel controller (23). The curves below the diagram of the fuel controller show how the air pressure varies as it passes through the intake system.

EQUIPMENT AND TEST METHODS

The first tests were run in the agricultural engineering laboratory on the Hercules engine. Plate I illustrates the engine as it was equipped. This is a model OOC, four cylinder, 4" x 4½" engine operating on the four stroke cycle. The rated

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[1]The refrigerating effect of the fuel as it expands and thus vaporizes as it passes the throttle valve causes temperatures of 32° F. and lower to be reached within the fuel. This effect causes the outside surface of the regulator to be very cold. The air touching this cold surface contains moisture which on being cooled will condense and freeze forming frost on the cold surface.

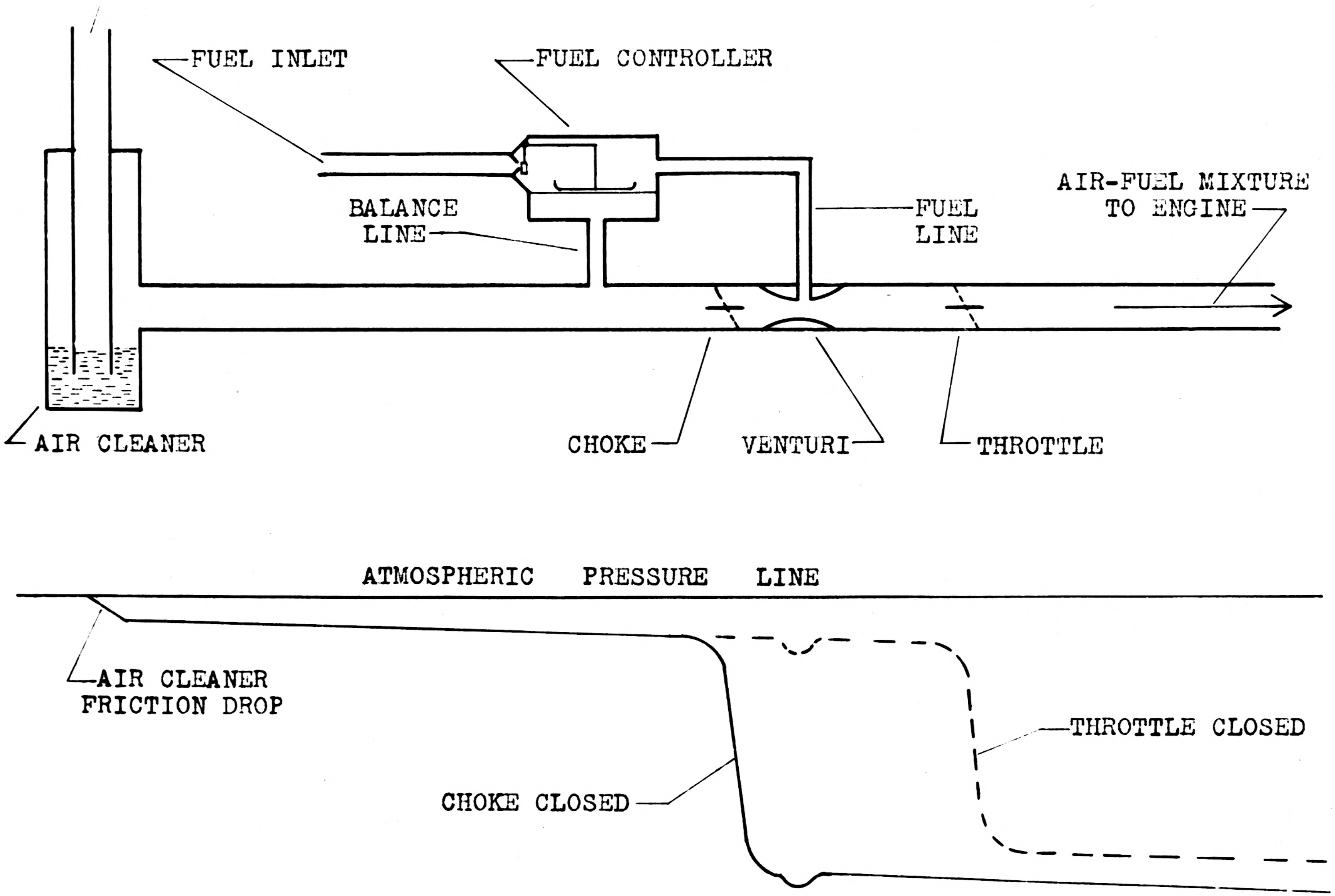
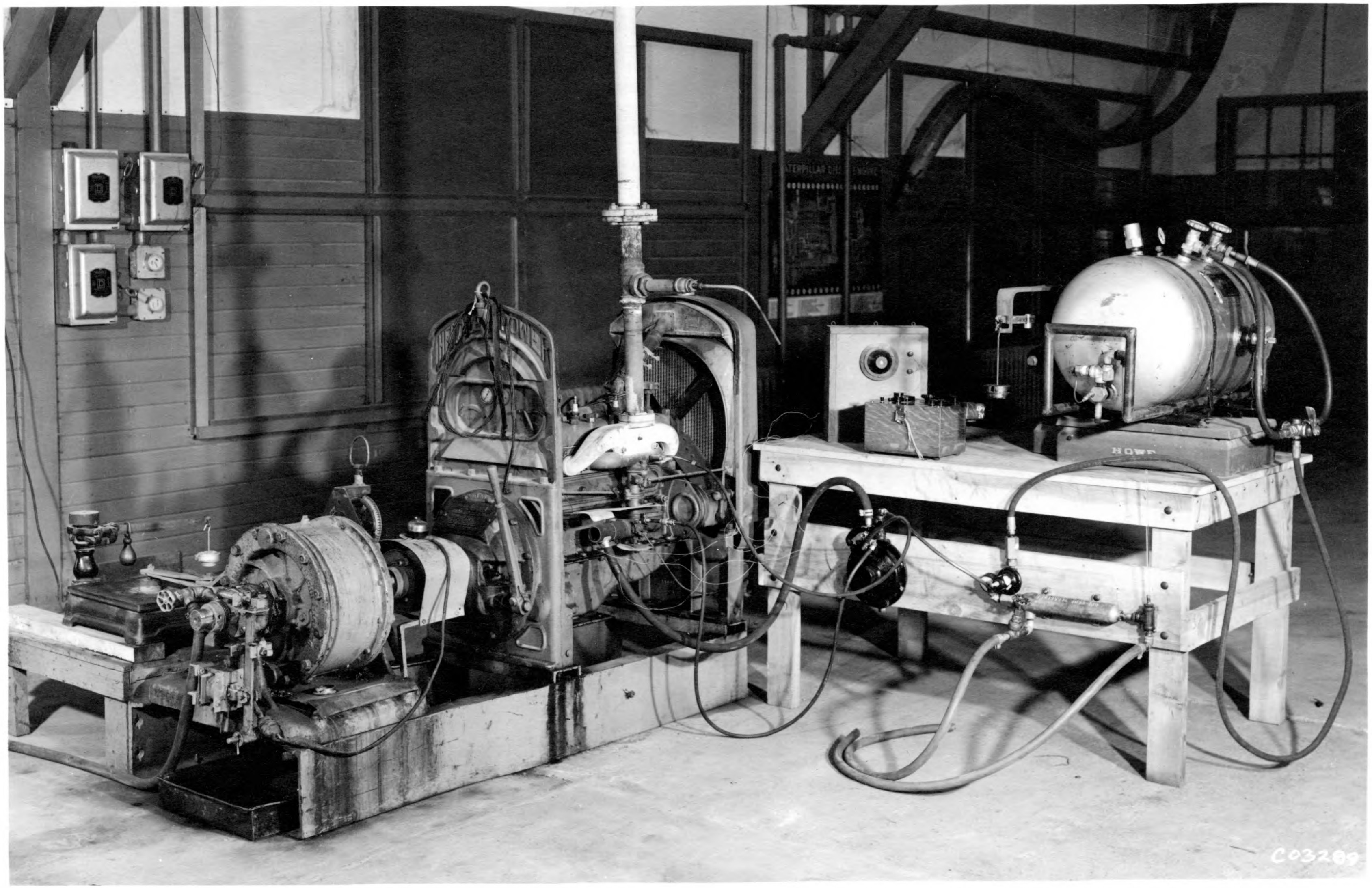


Fig. 5. Fuel controller and intake air depression curves.

EXPLANATION OF PLATE I

View of Hercules engine with equipment used in the tests.

PLATE I



rpm of the engine is 1200, and the compression ratio used was 3.73:1. The engine was connected directly to a Detroit hydraulic dynamometer. The load on the engine was controlled by adjusting the control on the dynamometer.

The table on which the scales and fuel tank are located was constructed so that the Garretson Uni-temp vaporizer and fuel controller could be mounted on the side and the whole unit moved about at will. A rack with handles was constructed for the fuel tank so that it could be carried about for refilling. The table was placed at the right hand side of the engine and close enough to make the necessary connections.

All of the instruments necessary for the tests were placed on the table in convenient locations for reading.

Plate II shows the instruments that were used on the Hercules engine.

Shown at the far right is the Electro products exhaust analyzer which was used to indicate the air-fuel ratios. Next to the analyzer, the water manometer and stopcock valve can be seen. These were used to determine and control the pressure of the exhaust gases at the inlet of the analyzer.

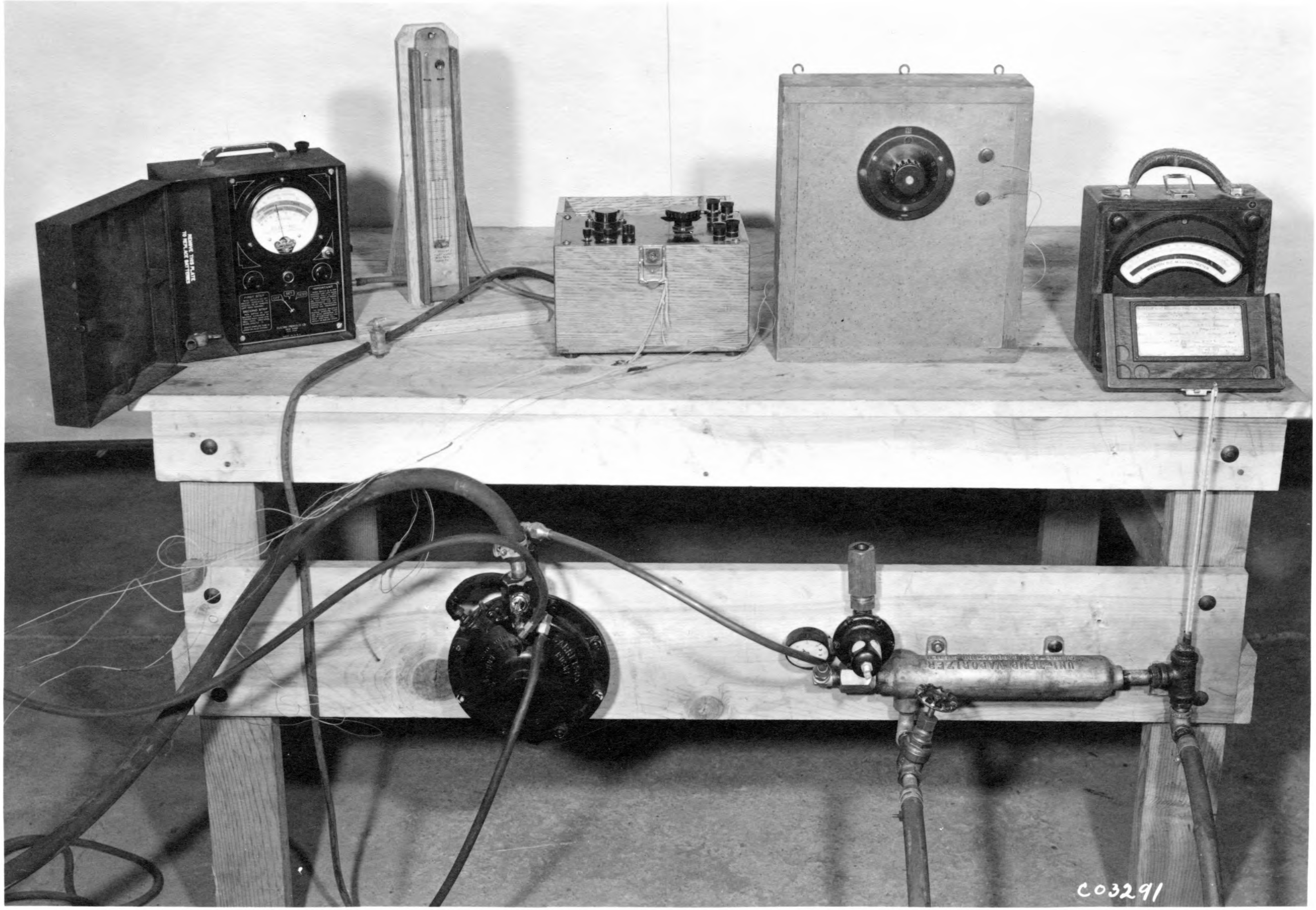
The potentiometer and junction box are shown in the center. The three thermocouples which were used to indicate the air, the fuel vapor, and the mixture temperature were connected to the junction box and the temperatures were indicated by the potentiometer directly in degrees Fahrenheit.

The instrument on the far right in Plate II is a millivoltmeter, which was connected to a small generator on the engine, and used to indicate fluctuation in rpm.

EXPLANATION OF PLATE II

View of table with instruments used in tests on the Hercules engine. The Garretson pressure injection controller with Uni-temp vaporizer are shown mounted on the table.

PLATE II



Other tests were run in the mechanical engineering laboratory on the Minneapolis-Moline engine. Plate III illustrates the engine as it was equipped. The engine is a four cylinder, 4 5/8" x 6", stationary type, operating on the four stroke cycle. The rated rpm of the engine is 1100 and the compression ratio used was 5.75:1. The engine was connected directly to the electric dynamometer.

The cooling system of the engine was made of a 6" pipe containing coils over which the engine cooling water was passed. Hydrant water was passed through the coils. A valve and flowrator were connected to the inlet so that the engine could be maintained at a constant coolant temperature.

The air box shown at the far right in Plate III was used to measure the air flow into the carburetor of the engine. The $2\frac{1}{2}$" square-edged orifice was calibrated in the mechanical engineering laboratory by a nozzle and Pitot tube. By obtaining the pressure differential across the orifice, the air temperature, the barometric pressure, and the wet bulb temperature, the air consumption in pounds per minute could be obtained by the following formula:

$$\text{Air flow in \#/minute} = C \times 0.0341 \times 1096.2 \sqrt{h/d} \times d$$

Where:

C = A constant obtained by calibration of the orifice

0.0341 = Orifice area in square feet

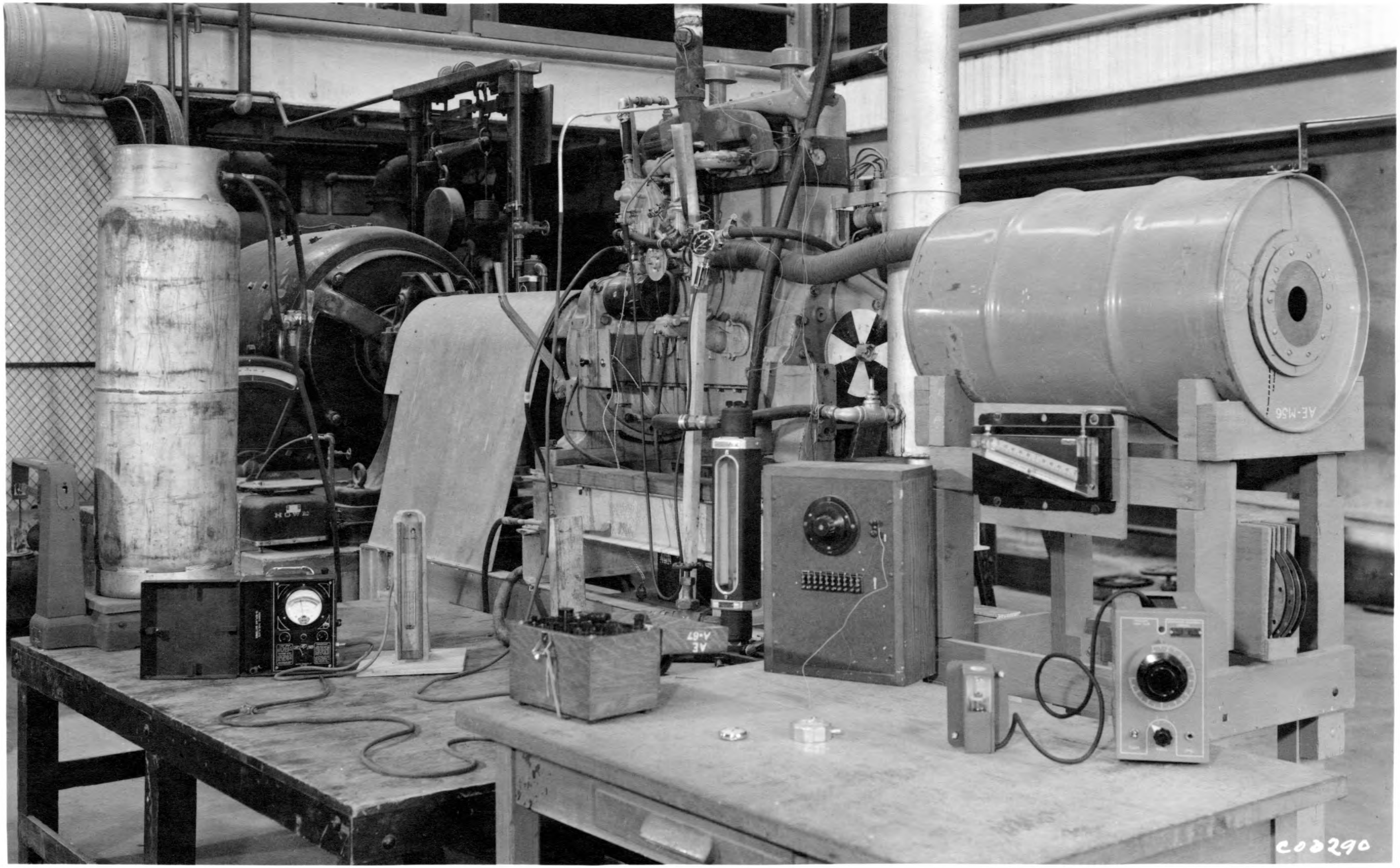
h = Pressure differential across orifice in inches water, draft gauge

d = Density of air in #/cubic foot

EXPLANATION OF PLATE III

View of the Minneapolis-Moline engine with the instruments and equipment used in the tests.

PLATE III



In calibrating the orifice, the air box was connected to a 8" diameter tube leading to a large suction fan. The tube contained the Pitot tube and nozzle. A throttle on the fan was used to vary the rate of air flowing.

In this way the quantity of air flowing through the orifice was measured at several points on the draft gauge of the air box.

The constant C was calculated for each point on the draft gauge at which a test was run. Three test runs were made, each covering the range of the air box draft gauge. The average value of C obtained from these runs is shown in Figure 6 at any given draft gauge reading.

The first series of tests were run on the Hercules engine connected to the hydraulic dynamometer in the agricultural engineering laboratory. The engine was thoroughly warmed up before the test data was taken. This usually required thirty minutes. The carburetor was adjusted so that the maximum power was being developed with open throttle. Tests were run at maximum, 80 percent, 60 percent, 40 percent, and minimum loads, with the carburetor adjustment remaining the same throughout the load range. The ignition timing was adjusted for maximum power at open throttle, and remained the same throughout the tests. The brake load was measured by the scales at the side of the dynamometer. The rpm of the engine was determined by a revolution counter geared to the driveshaft of the dynamometer. The counter was allowed to run during the total test time. Thus, the total revolutions divided by the time gave the average rpm of the engine during the test. The horsepower of the engine was

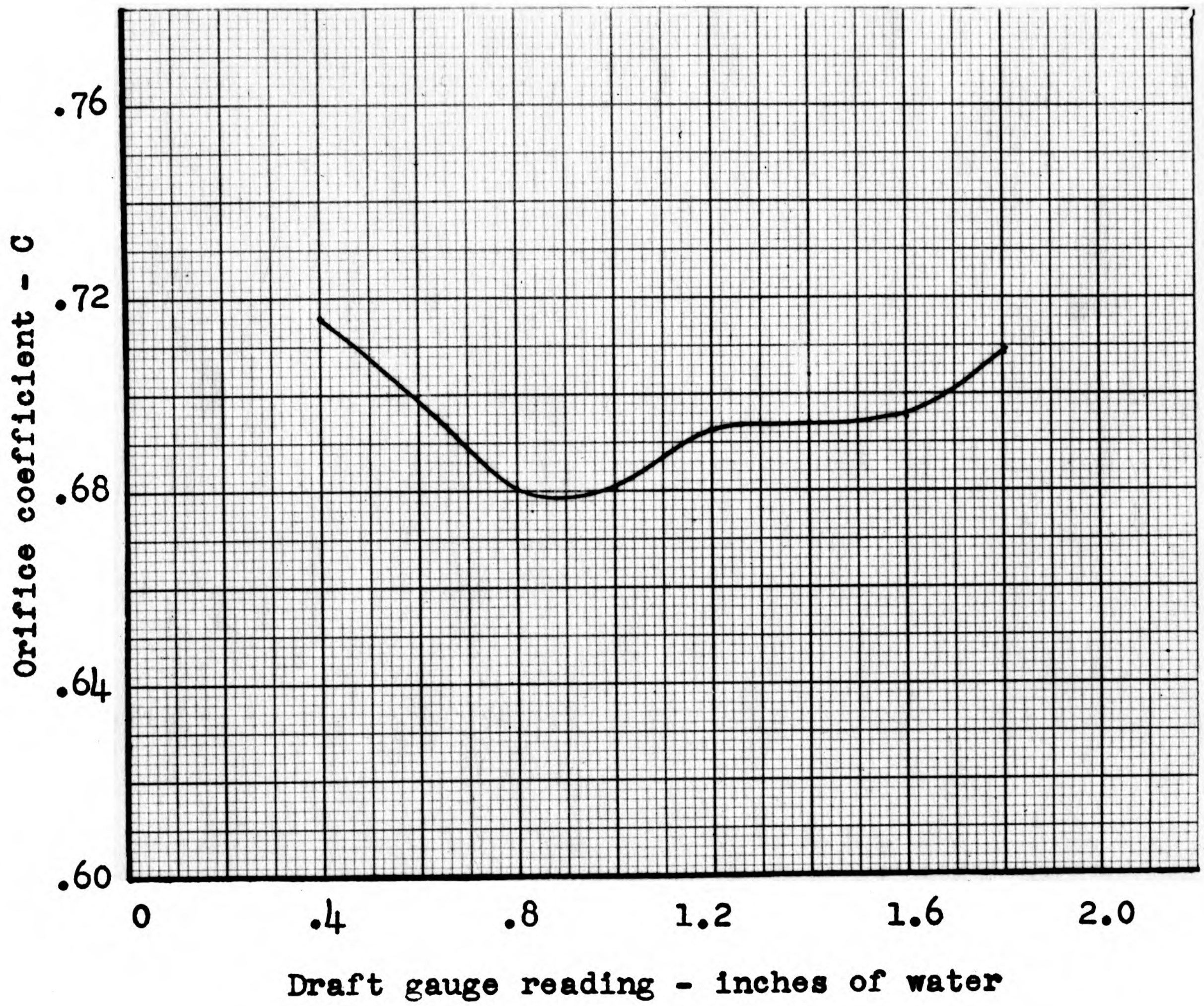


Fig. 6. Calibrated orifice coefficient.

was determined from the hydraulic dynamometer by the following formula:

Brake Hp = rpm x brake load x 0.0004

Where:

rpm = speed of engine in revolutions per minute

0.0004 = brake constant

Brake load = net weight in pounds

The fuel consumption was measured by placing a fuel container on the Howe scales which was graduated to 1/100 of a pound. The beam was balanced with a slight up weight while the engine was running under test conditions. As the fuel was removed, the beam moved slowly toward the center balance mark. As the beam passed the center mark, the stop watch was started. Usually the tests were run for ten minutes. As the time approached the ten minute mark, the scale was balanced with a slight up weight, and the small sliding weight on the weigh beam was adjusted so that the beam was at the center balance just as the time passed the ten minute mark.

This procedure of weighing the fuel resulted in more accuracy than was obtained during the first few trials when two fuel tanks were used. Each of the two fuel tanks had been connected individually to the engine with the fuel being drawn from either tank by a two-way valve. One tank was placed on the Howe scales and the other was used as an auxiliary for warmup and adjusting periods. The scale was balanced while the engine was operating on the auxiliary tank. At the desired time for the test to start the two-way valve was turned, and the stop watch started simultaneously.

At the end of the ten-minute test, the two-way valve was turned to the auxiliary tank again and the amount of fuel consumed was determined. However, several inconsistent and unreasonable readings were obtained and the method previously described was tried and found to be very satisfactory.

The temperature of the fuel vapor, the entering air, and the air-fuel mixture were taken with thermocouples as described on page 53. These readings were taken at least three times during the ten-minute test and the average recorded. However, it was found that the temperature remained constant through each test.

The air-fuel ratio was obtained during each test by the Electro products exhaust gas analyzer. The exhaust manifold was tapped with a ¼-inch pipe to which the analyzer was connected by a rubber tube. After several runs it was found that the air-fuel ratios were not consistent throughout the load range. This was attributed to the change in pressure of the exhaust gases to the analyzer as the throttle opening was changed. A small water manometer was connected to the rubber tube with a glass tee and a small glass stopcock valve connected to the end of the tube. The exhaust gases were throttled by the valve at maximum load so that the pressure as indicated by the manometer was the same as it was at minimum load. In this way the exhaust gases were provided at constant pressure to the analyzer. A back pressure of one inch water column was used for all tests. The indicated air-fuel ratios were much more consistent after this arrangement was used.

At least three readings of the exhaust analyzer were taken during each ten-minute test. The rubber tube was disconnected from the analyzer after each reading, and the exhaust gas removed from the analyzer chamber by the aspirator. According to the instruction book for the analyzer this was not necessary as the analyzer is not affected by moisture in the exhaust gas, but this was done to see that the instrument was still in balance.

The manifold pressure was obtained by tapping the intake manifold with a ¼-inch pipe, and by attaching the rubber hose of the manifold pressure gauge.

The purpose of the first series of tests was to compare the fuel consumption of the Garretson pressure injection system with the conventional fuel controller referred to as the Perma-Balance fuel controller.

The engine was first equipped with the Garretson pressure injection carburetor. A rubber hose six inches long was clamped onto the intake air horn of the carburetor. The fuel line hose was inserted into the side of this hose. Thus, the point of injection of the vapor was just in front of the choke plate which is the most common point of connection.

After a series of tests had been run on the pressure injection carburetor, this regulator was removed and the Perma-Balance fuel controller was mounted in its place. The change from one regulator to the other was very easy because the mounting bracket and fuel line connections are the same. The only change in connection is the point at which the fuel enters the air stream. The same fuel line hose was used, but was connected to the venturi fuel nozzle. Suitable fittings were required here, but since the carburetor had already been adapted to LP Gas, no special type of fittings were required. The change required only twenty minutes. A series of tests were run which were identical with those using the pressure injection carburetor.

Another series of tests was run on the Minneapolis-Moline engine connected to an electric dynamometer in the mechanical engineering laboratory. The engine was thoroughly warmed up before any test data were taken, this usually required from thirty to forty minutes. The brake load was measured by scales attached to the dynamometer. The load on the engine was controlled from a control panel across the room.

The carburetor was adjusted for maximum power with the throttle open. Tests were run at ten percent ranges of the maximum horsepower with the carburetor adjustment remaining the same as for maximum power. The spark was adjusted for maximum power at open throttle and this setting was used throughout the tests. The test time was ten minutes.

A stroboscope, facing a disk attached to the crankshaft and painted alternately in quadrants of black and white, was used to indicate fluctuations in rpm. The rpm of the engine was determined by a revolution counter. Three to five readings were taken during each ten minute test and the average rpm was used as the actual rpm. The horsepower of the engine was determined from the electric dynamometer by the following formula:

$$\text{Brake hp} = \frac{\text{Brake load} \times \text{rpm}}{3000} + 0.45$$

Where:

Brake load = net weight in pounds

rpm = speed of engine in revolutions per minute

0.45 = friction and windage hp loss of dynamometer at 1100 rpm

The fuel consumption was measured by the same method employed with tests on the Hercules engine as described on page 40.

The temperature of the fuel vapor, the entering air, and the mixture was taken by the same method as described on page 53. The temperature of the exhaust gases was measured with thermocouples at two places. One thermocouple was inserted into the exhaust manifold at the front cylinder port. The other thermocouple was inserted into the exhaust pipe at the point where the exhaust gases from the four cylinders were joined together.

All of the temperatures were read at least three times during each ten-minute test. It was found that all the temperatures remained constant through each test, and no average was needed.

The indicated air-fuel ratio was obtained during each test by the Electro products analyzer using the same method that was used on the Hercules engine as described on page 41.

The air-fuel ratio was also measured by the air box fitted with the two and one-half inch diameter square-edged orifice.

At greater than eighty percent of the power output of the engine the draft gauge fluctuated as much as .06 inches from a low reading to a high reading. The fluctuation was worse at maximum power, and became progressively weaker in the lower range of power. It was very steady at thirty percent of maximum power.

Like the other readings, the draft gauge was read three times during each ten-minute test. The rpm was read at the same time the draft gauge was read so that the correlation of air flow and rpm would be more consistent.

The manifold pressure was obtained by tapping the intake manifold with a ¼-inch pipe and attaching the rubber hose of the manifold pressure gauge.

The purpose of this series of tests was to compare the fuel consumption of the Garretson pressure injection system with the conventional carburetor with which the engine was equipped, and also to compare the performance of the Garretson pressure injection system and the Perma-Balance fuel controller when used on a larger engine with the results obtained on the Hercules engine.

The engine was first equipped with the Ensign LP Gas carburetion equipment. After the fuel consumption tests were completed, the Ensign equipment was removed and the Garretson Perma-Balance fuel controller and Uni-temp vaporizer were attached to the engine. This change involved considerable time and effort. A gasoline carburetor had to be equipped for LP Gas by inserting a fuel nozzle through the bottom of the carburetor up to the smallest diameter of the venturi. The fuel controller and vaporizer were mounted on a stand beside the engine so that the hot water connection could be made as short as possible. The fuel line from the controller was then attached to the bottom of the carburetor.

It was evident very soon after starting the engine for the warm-up period that the vaporizer unit was inadequate to furnish enough heat for the rate of fuel vaporization required by this engine. The only thing that could be done at this time was to use an old Ensign vaporizer unit which furnished an ample amount of heat. After the test runs on the Perma-Balance fuel controller were completed, the fuel controller was removed and the pressure injection controller mounted in its place.

The Garretson pressure injection system was mounted very easily in place of the Garretson Perma-Balance fuel controller. The same carburetor was used with the pressure injection carburetor as was used with the Perma-Balance fuel controller. The fuel inlet connection was made in the rubber tube just ahead of the choke plate. This connection was the same as was used on the Hercules engine.

Table 4 and Fig. 7 show in detail the results obtained on the Hercules engine. The engine developed about the same maximum brake horsepower with the two units. The fuel consumption was practically the same at maximum power. From maximum power to about 70 percent of maximum power the pressure injection system provided a smaller specific fuel consumption than the Perma-Balance. However, this trend was reversed below 70 percent power. The air-fuel ratio provided by the Perma-Balance controller was more nearly constant throughout the load range than that provided by the pressure injection system.

Table 4. Fuel consumption of Hercules engine.

Per-cent load*	r.p.m.	Brake h.p.	Fuel consumption #.hr.	Fuel consumption #/b.h.p. hr.	Air temp. °F.	Fuel vap. temp. °F.	Mixt. temp. °F.	Air-fuel ratio⁑	Man. inches Hg
Test No. 1. Garretson pressure injection carburetor liquid withdrawal, Uni-temp vaporizer									
100	1194	24.25	16.1	0.665	92	73	91	14.2	2.0
90	1203	21.40	13.9	0.650	94	77	95	15.2	4.0
80	1201	19.45	12.6	0.647	95	80	93	15.5	5.2
70	1200	16.60	10.8	0.654	95	81	93	14.8	7.0
60	1194	14.20	10.1	0.710	95	83	95	14.85	10.0
40	1208	9.80	8.7	0.888	96	88	98	14.75	13.0
Min.**	1195	5.74	7.28	1.270	96	88	95	14.70	15.6
Test No. 2. Garretson Perma-Balance fuel controller liquid withdrawal, Uni-temp vaporizer									
100	1194	24.00	15.90	0.660	81	72	81	14.3	2.0
80	1202	19.45	13.06	0.671	83	75	82	14.8	5.1
60	1193	14.55	9.50	0.652	80	76	80	14.9	10.5
40	1185	9.60	7.80	0.813	80	77	80	15.0	14.0
Min.	1192	5.50	6.60	1.200	80	80	80	15.2	15.4

* Average of all runs with this equipment at this load.

** Minimum brake load obtainable.

⁑ Indicated air-fuel ratio by exhaust analyzer.

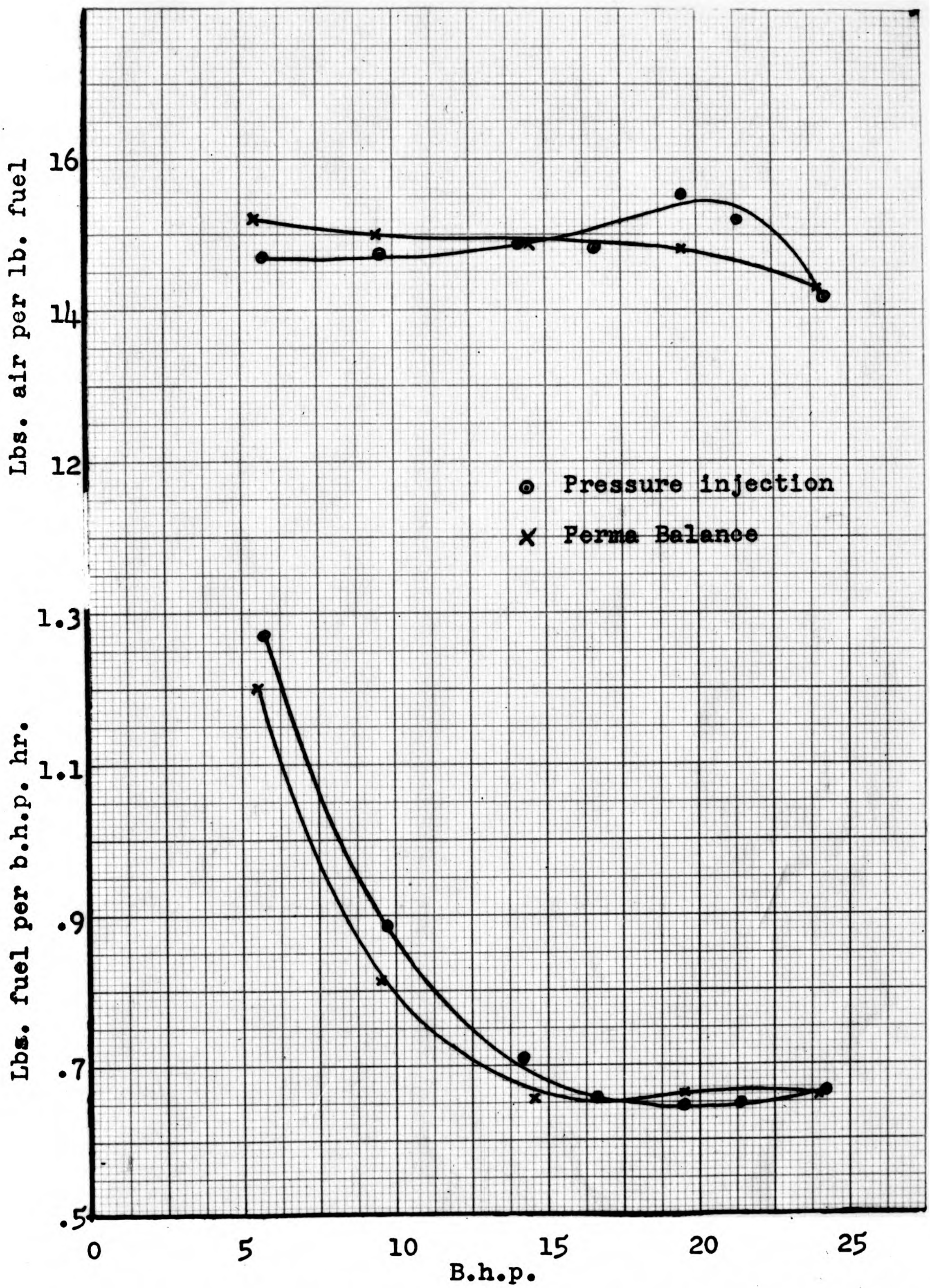


Fig. 7. Specific fuel consumption and indicated air-fuel ratio of two types of carburetion systems - Hercules engine.

Table 5 and Fig. 8 show the results obtained from tests on the Minneapolis-Moline engine. The maximum power developed by the engine was greatest when the Ensign carburetion system was used. By referring to Table 5 the corrected maximum power for each of the systems is as follows:

Type of carburetion system	Corrected max. h.p.
Ensign carburetor	62.75
Perma-Balance fuel controller with adapted carburetor	59.1
Pressure injection carburetor	57.0

The corrected maximum horsepower was determined by the following formula:

$$\text{Correct maximum hp} = \text{bhp} \times \frac{Ps}{Po} \times \sqrt{\frac{To}{Ts}}$$

Where:

bhp = Brake horsepower.

Ps = Standard barometric pressure @ 29.92 inches of mercury.

Po = Observed barometric pressure.

Ts = Standard absolute temperature @ (460 + 60) °F.

To = Observed absolute temperature.

The difference in maximum power between the Ensign system and the Perma-Balance system was attributed to the difference in the cross sectional area of the carburetor venturi throat. The area of the Ensign carburetor venturi was 0.9925 square inches. The area taken up by the fuel nozzle was 0.15 square inches, leaving 0.8425 square inches through which the air could flow.

Table 5. Fuel consumption of Minneapolis-Moline engine.

Per-cent load	r.p.m.	Brake h.p.	Fuel consumption #/hr.	Fuel consumption #/b.h.p. hr.	Air consumption Temp. °F.	Air consumption Draft gauge inches water	Air consumption #/min.	Measured air-fuel ratio	Indicated air-fuel ratio	Exhaust temp. °F.	Fuel vap. temp. °F.	Mixt. temp. °F.	Manifold inches Hg
Test No. 3. Ensign vaporizer and carburetor with economizer operating													
100	1115	59.25	34.5	0.584	86	1.64	8.7	15.1	13.8	1130*	138	86	2.0
90	1098	51.25	34.2	0.666	86	1.48	8.37	14.7	12.7	1100	132	86	2.8
80	1098	45.65	33.0	0.721	86	1.16	7.35	13.8	-	1060	130	87	5.0
70	1103	40.05	28.5	0.711	87	0.95	6.63	13.8	-	1070	133	87	7.0
60	1100	34.35	21.0	0.612	87	0.72	5.76	16.4	14.25	1130	140	91	9.0
40	1100	23.05	15.6	0.676	87	0.44	4.77	18.3	14.80	1110	148	91	12.5
10	1100	6.1	9.3	1.520	86	0.16			14.25	970	160	96	17.6
Corrected maximum h.p. for Test No. 3 = 62.75								Barometer (obs.) = 28.82" Hg; wet bulb = 76° F.; dry bulb = 85° F.					
Test No. 4. Garretson Perma-Balance fuel controller													
100	1100	56.05	33.0	0.588	83	1.54	8.54	15.60	13.90	1120	138	84	2.0
90	1098	51.45	33.0	0.643	83	1.31	7.92	14.42	12.75	1100	138	84	3.0
80	1099	45.55	30.8	0.675	84	1.12	7.12	13.90	-	1070	139	85	5.5
70	1102	40.05	28.8	0.719	84	0.93	6.50	13.55	-	1070	141	86	7.0
60	1105	34.45	26.1	0.757	84	0.77	5.92	13.60	-	1050	139	86	9.0
40	1103	23.15	20.0	0.865	84	0.47	4.74	14.20	-	1030	135	86	13.0
10	1100	6.1	11.0	1.80	84	0.18			-	950	130	87	17.0
Corrected maximum h.p. for Test No. 4 = 59.1								Barometer (obs.) = 28.95" Hg; wet bulb = 73° F.; dry bulb = 82° F.					
Test No. 5. Garretson pressure injection carburetor													
100	1102	53.75	33.4	0.621	91.5	1.51	8.37	15.05	13.9	1110	142	95	2.0
90	1099	51.45	32.4	0.630	91.5	1.38	8.0	14.80	13.75	1100	143	95	3.0
80	1099	45.75	30.5	0.667	91.5	1.16	7.35	14.40	12.75	1090	146	95	5.0
70	1098	39.95	27.9	0.70	91.5	0.94	6.60	14.15	-	1080	145	97	7.0
60	1102	34.55	25.5	0.740	91.5	0.77	5.96	14.30	-	1070	145	97	9.0
40	1097	23.10	21.0	0.970	91.5	0.48	4.71	14.30	-	1050	142	98	13.0
10	1130	6.25	11.55	1.850	91.5	0.20	3.04	15.7	12.25	930	138	100	17.0
Corrected maximum h.p. for Test No. 5 = 57.0								Barometer (obs.) = 28.82" Hg; wet bulb = 79° F.; dry bulb = 89° F.					

* Temperature front cylinder port

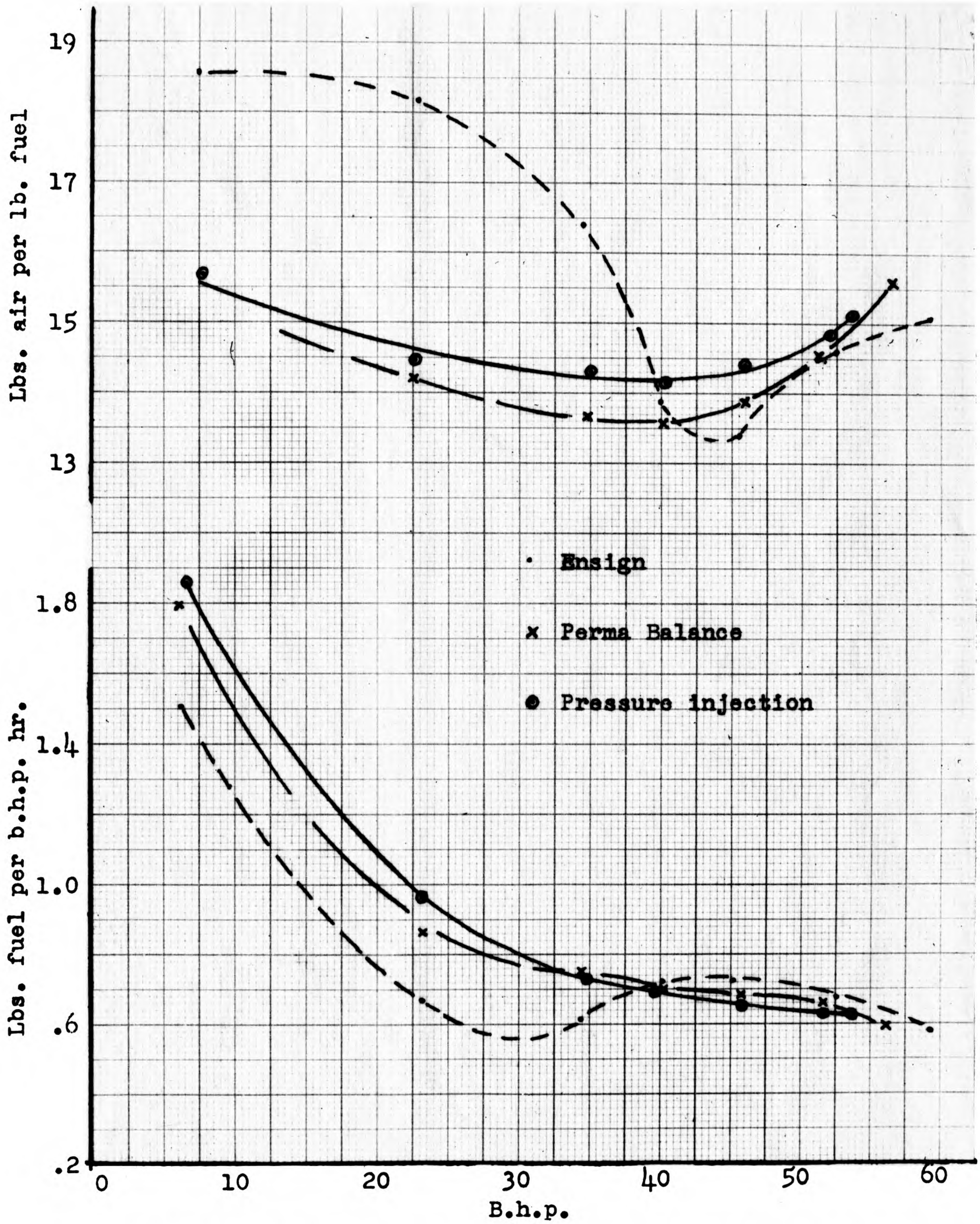


Fig. 8. Specific fuel consumption and measured air-fuel ratio of various carburetion systems - Minneapolis Moline engine.

The area of the venturi of the converted gasoline carburetor was 0.885 square inches. The area taken up by the LP Gas fuel nozzle and the gasoline nozzle was 0.1686 square inches leaving 0.6164 square inches through which the air could enter.

The difference between the two net areas is 15 percent resulting in the loss of power.

The loss of maximum power between the Perma-Balance system and the pressure injection system was believed to be due to the relative positions where the fuel vapor entered the air. The fuel was injected ahead of the choke plate and at least six inches ahead of the venturi. Apparently, the longer residual time of the fuel vapor in the intake system allows the mixture temperature to increase as noted from the data in Table 5. A higher mixture temperature indicates a less dense intake charge which results in less power output.

By referring to the fuel consumption curves of Fig. 8 the characteristics of the fuel controllers may be seen. The Ensign carburetor with economizer begins to lean out at about 72 percent load and has a lower specific fuel consumption than the others at loads less than 70 percent power.

The pressure injection system and the Perma-Balance fuel controller have the same general shape. The similarity of these two curves with those of Fig. 7 should be noted. The Perma-Balance again provides the smaller specific fuel consumption at loads less than 70 percent. The fuel consumption of these two controllers at maximum power is about equal and both provide practically the same corrected maximum power.

The air-fuel ratios shown in Fig. 8 were measured with the air box and orifice. When the fuel adjustment was controlled to give maximum power on the Minneapolis-Moline engine the analyzer would read about 13.9. At part-loads the analyzer would go off the scale.

In the second series of tests the effect of the fuel vapor temperature upon the air-fuel ratio and fuel consumption was determined. The Hercules engine was equipped with the Garretson pressure injection system and Uni-temp vaporizer. The fuel was injected at a point just in front of the choke plate. A thermocouple was inserted into the fuel line hose at a point just before the fuel entered the air stream. A thermocouple was inserted into the air stream at a point just before the fuel was admitted to the air, and a thermocouple was inserted into the air-fuel mixture at a point just after the fuel was injected into the air.

With the thermocouples located in these positions it was possible to determine the temperature of the fuel vapor, the entering air, and the air-fuel mixture. A shield of aluminum was placed between the exhaust manifold and the thermocouples to prevent the radiant heat of the exhaust from affecting these indicated temperatures.

For consideration of the effect of the fuel vapor temperature upon fuel consumption the fuel vapor temperature had to be controlled. To accomplish this, a valve and thermometer were placed in the hot water line going to the fuel vaporizer. The valve allowed the water flow to be controlled so that the refrigerating effect of the fuel would attain a certain temperature of the fuel as it left the fuel vaporizer. The Minneapolis-Moline engine was equipped with thermocouples in the same manner. However, the Ensign carburetion equipment was used on the Minneapolis-Moline engine. The temperature of the fuel vapor at the point it entered the air was the only thing under consideration so whatever happened in the vaporizer was not important. It was merely a way of controlling the fuel vapor temperature. The thermometer was placed in a well in the hot water line so that it could be determined when a constant water temperature was attained. However, the thermometer was relatively ineffective when the temperature of the water was near the freezing point. The thermometer was not sensitive enough at this temperature and it was as easy to control the water flow by the thermocouple temperature as by the thermometer.

It was found that at least thirty minutes was required to establish a constant fuel vapor temperature in the low ranges. A very slight movement of the valve would greatly affect the fuel vapor temperature; i.e., from 10° F. above to 10° F. below the desired temperature. No anti-freeze was added to the water in the Hercules engine, therefore, caution was exercised in not letting the water temperature go below the freezing point. An anti-freeze solution was added to the cooling system of the Minneapolis-Moline engine; therefore the fuel vapor temperature could go below freezing.

In the higher ranges of the fuel vapor temperature, an accurate control of the vapor temperature was more easily obtained. The thermometer in the water line was very effective here in obtaining a constant fuel vapor temperature.

Figure 9 shows the effect of the load on the fuel vapor temperature of the Garretson Uni-temp vaporizer and the Ensign vaporizer. These temperatures were taken as the load was varied during the fuel consumption tests.

Table 7 and Fig. 10 show the effect of the fuel vapor temperature on the fuel consumption and the air-fuel ratio as run on the Hercules engine at 100 percent load. The range in fuel vapor temperature could be extended to a much lower range than could be obtained at either 75 percent or 50 percent load. This is because the fuel-flow rate is reduced and therefore the refrigerating effect is lessened.

It should be noted in the curves of Fig. 10 that the specific fuel consumption at 75 percent load is slightly less than the specific fuel consumption at 100 percent and that the specific fuel consumption at 50 percent is quite large compared to the specific fuel consumption at 100 percent. This is in agreement with the specific fuel consumption curves of Fig. 7, page 48.

Table 8 and Fig. 11 show the effect of the fuel vapor temperature on the fuel consumption and the air-fuel ratio as run on the Minneapolis-Moline engine. The fuel consumption shows the same trend as is shown in Fig. 10.

The air-fuel ratios shown in Fig. 11 are of interest. The air-fuel ratio was taken with the Electro products exhaust

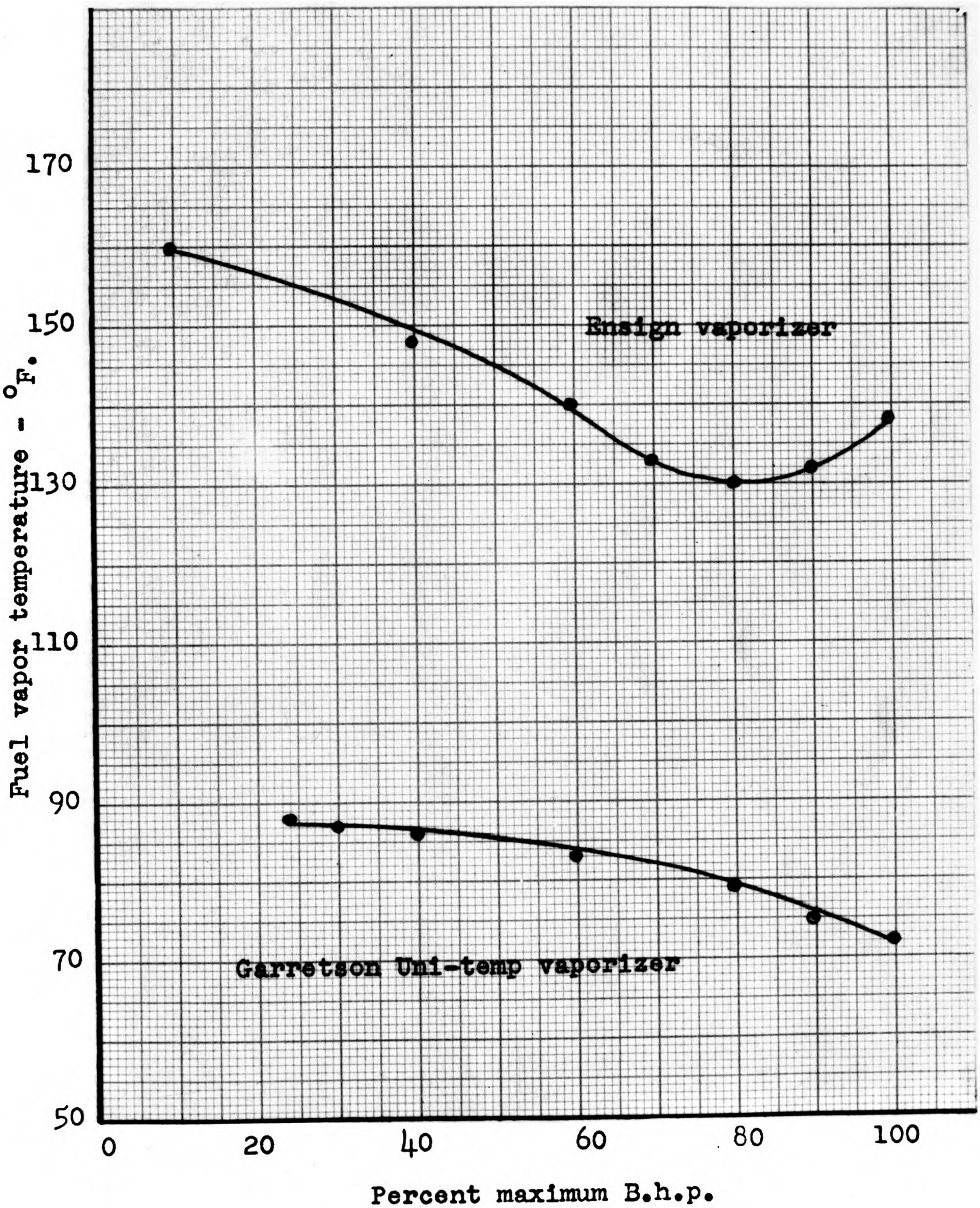


Fig. 9. Effect of load on fuel vapor temperature.

Table 7. Effect of fuel vapor temperature on specific fuel consumption and air-fuel ratio.

h.p.	Fuel vapor temp. °F.	Entering air temp. °F.	Mixture temp. °F.	# Fuel/hr.	# Fuel/b.h.p. hr.	Air-fuel ratio
	Garretson pressure injection carburetor @ 100% load on Hercules engine					
23.7	114	98	101	14.5	.612	14.5
23.9	102	93	96	15.1	.631	14.5
23.9	85	96	95	16.3	.673	14.24
24.2	54	91	85	17.3	.715	13.4
24.2	46	90	85	17.5	.718	13.0
24.4	30	89	80	18.0	.736	12.8
				@ 75% load		
17.6	108	100	104	10.8	.614	15.5
17.6	82	98	97	11.5	.654	15.0
17.6	77	99	96	11.8	.666	14.8
17.6	61	100	95	12.0	.682	14.45
				@ 50% load		
12.0	108	103	102	10.2	.850	15.2
12.1	86	98	97	10.8	.895	14.25
12.1	77	97	95	11.4	.943	14.1

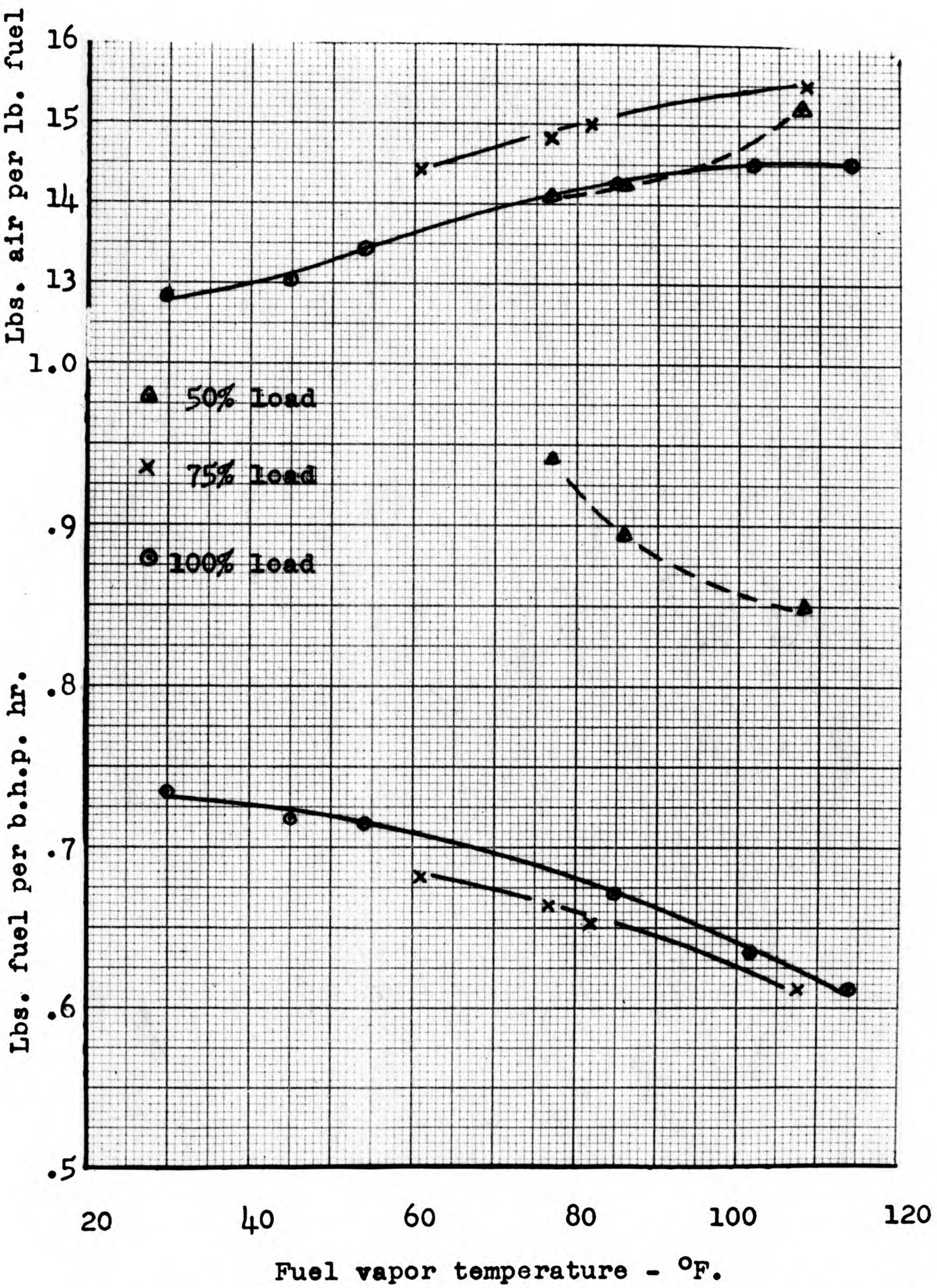


Fig. 10. Effect of fuel vapor temperature on specific fuel consumption and air-fuel ratio - Hercul engine.

Table 8. Effect of fuel vapor temperature on specific fuel consumption and air-fuel ratio.

h.p.	Fuel vapor temp. °F.	Entering air temp. °F.	Mixture temp. °F.	# Fuel per hr.	# Fuel per b.h.p. hr.	Air-fuel ratio ind.	Air-fuel ratio air box
Minneapolis-Moline engine @ 75% load on Ensign carburetor							
43.55	144	75	81	24.0	.550	15.10	17.05
43.35	135	78	80	24.0	.555	14.80	17.05
43.30	121	79	80	24.4	.564	14.60	16.77
43.30	109	80	80	24.7	.571	14.50	16.55
43.35	92	81	79	25.5	.590	14.25	16.01
43.45	48	81	76	25.8	.595	13.70	15.85
43.35	10	81	70	26.5	.612	13.20	15.42
@ 50% load							
29.20	145	78	85	18.55	.635	14.6	17.23
29.10	130	78	84	18.75	.644	14.4	17.05
29.05	103	80	83	19.25	.662	13.9	16.42
29.10	75	84	82	19.80	.680	13.6	16.00
29.10	35	83	77	20.60	.706	12.8	15.50
29.10	4	80	72	20.80	.715	12.6	15.38

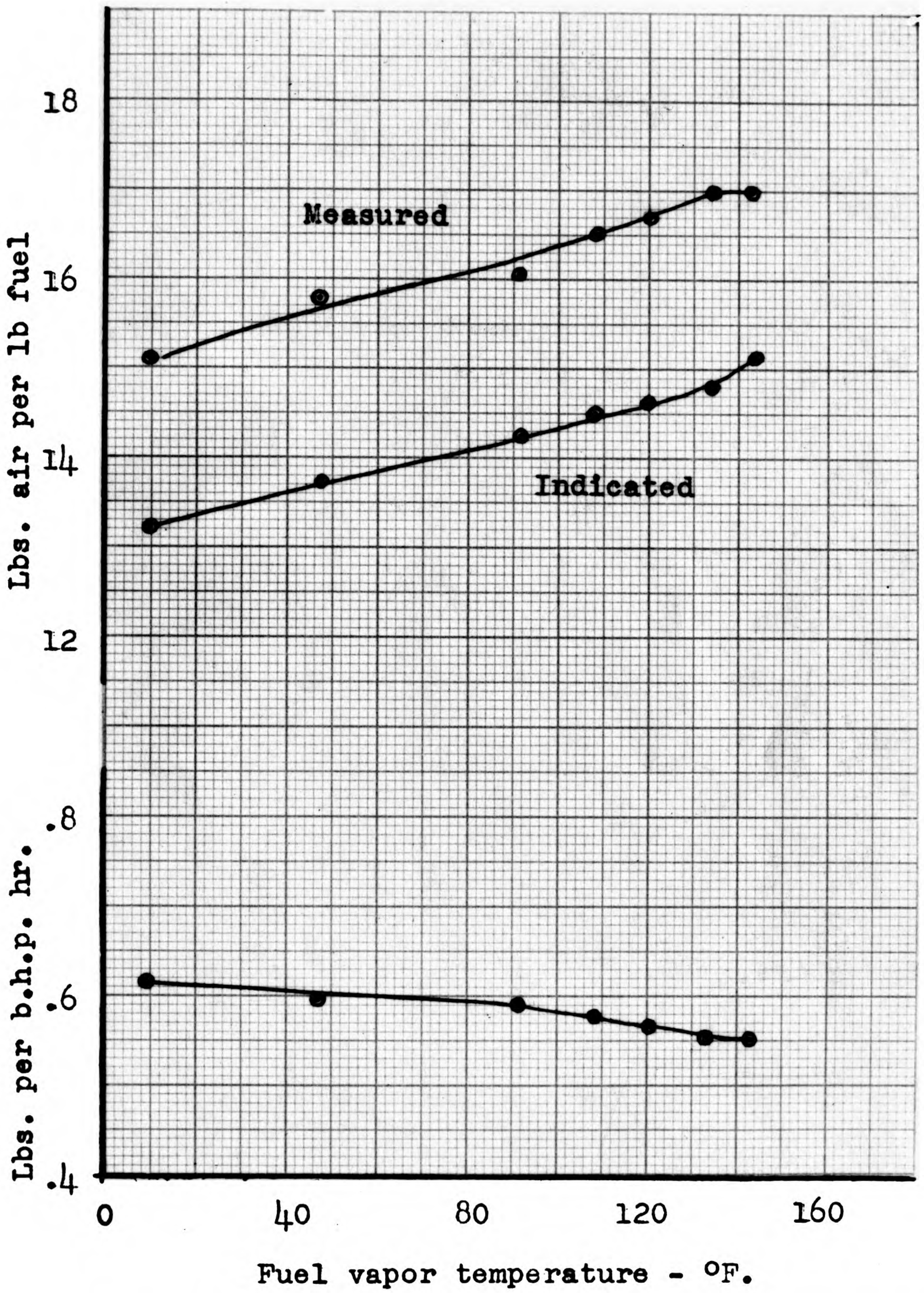


Fig. 11. Effect of fuel vapor temperature on specific fuel consumption and air-fuel ratio - Minneapolis Moline engine at 75 percent of maximum horsepower.

analyzer and also by the air box with square edge orifice. One might be led to believe that either the readings of the exhaust analyzer or the air box are inaccurate. However, the work of Paul and Popovich (16) shows that these readings are in relatively close agreement with their results. Figure 12 is a curve showing the correlation found by Paul and Popovich between the air-fuel ratio indicated by the Electro products exhaust analyzer and measured air flow.

By reading a point of indicated air-fuel ratio from Fig. 11 and directly above it read the measured air-fuel ratio. This measured air-fuel ratio can then be read on Fig. 12 and the indicated ratio from Fig. 12 is in close agreement with those indicated by the exhaust analyzer used in these tests.

The air-fuel ratio for maximum power is given by Paul and Popovich as 15.1:1. This is measured air-fuel ratio and the indicated ratio would be close to 13.5 reading from Fig. 12. This is close to the ratio indicated for the maximum power of these tests (Table 5).

SUMMARY AND CONCLUSIONS

In summarizing the results of this study it might be well to review the objectives of the investigation.

The objectives as set forth were:

1. To compare the performance of the pressure injection carburetor with the conventional carburetors as to:

   a. Maximum power developed

   b. Fuel consumption

   c. Ease of starting

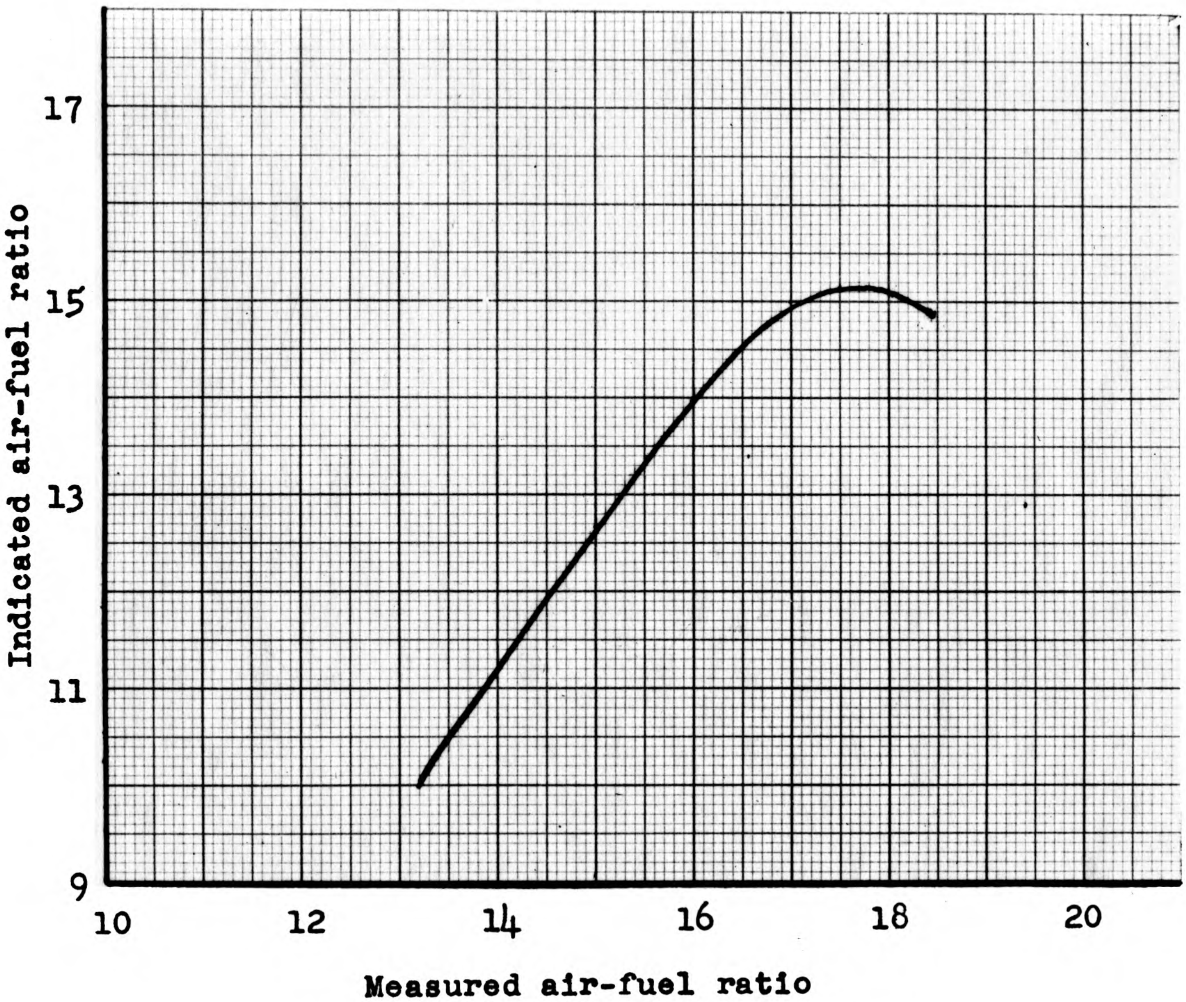


Fig. 12. Calibration of thermal conductivity type air-fuel ratio instrument.

d. Ease of adjustment

e. Ease of adapting to engine

2. To determine the effect of the fuel vapor temperature on:

a. Fuel consumption

b. Air-fuel ratio

The first objective, "maximum power developed," was studied by the tests which were run in determining the fuel consumption. Each of the carburetors was adjusted to give maximum power during each of these tests; therefore a comparison can be drawn. In tests on the Minneapolis-Moline engine the Perma-Balance fuel controller allowed the engine to develop slightly more power than the pressure injection system. However, the Ensign system provided the greatest power output of those tested. The corrected maximum power developed with each setup as listed on page 49 are:

Type of carburetion system	Corrected max. h.p.
Ensign carburetor	62.75
Perma-Balance fuel controller with adapted carburetor	59.1
Pressure injection carburetor	57.0

As the second objective was "fuel consumption" the results are shown in Figs. 7 and 8. The characteristics of the pressure injection and Perma-Balance controller are similar. These two, however, differ from the Ensign system. The characteristics of each of the systems tested were to be a little too rich at part-loads when they were adjusted to give maximum power.

"Ease of starting," the third objective, is usually a question asked about carburetion equipment, especially the LP Gas systems. In that the Hercules engine had to be hand-cranked and the Minneapolis-Moline engine was equipped with a starter a good comparison could be obtained.

The pressure injection system was a little harder to start on the Hercules engine at first, but soon a method was worked out and it started very easily. No trouble was experienced with starting on the Minneapolis-Moline engine. However, the two engines were inside in a warm room, whereas cold weather could affect the ignition and cause hard starting.

No trouble was experienced in starting when the equipment was changed from one engine to another. The fuel control adjustment could be changed after starting to get the smoothest engine operation.

Lastly, under the main objective of "to compare the performance of the pressure injection carburetor with the conventional carburetors," the problem of "ease of adjustment and adapting to the engine" was studied by the changing of equipment from one engine to another. Even though the individual carburetion systems were not permanently mounted on the engines, the fuel line and control line connection had to be made in any case. It was found that with the common tools to be found on any farm, the equipment could be changed quickly and easily except for converting the gasoline carburetor to LP Gas.

In determining "the effect of the fuel vapor temperature" on the "fuel consumption" it was found that the fuel vapor temperature affects the fuel consumption inversely as the vapor temperature changes. The curve for maximum power in Fig. 11 shows that for an increase of 20° F. in fuel vapor temperature gives a decrease of .04 pounds per bhp hr. or about a 6 percent decrease.

The air-fuel ratio is directly affected by the fuel vapor temperature's fluctuations.

Although it was not an objective of the investigation, it was found that the fuel vapor temperature did not greatly affect the mixture temperature, but does tend to directly affect the mixture temperature as can be seen by inspection of the performance data.

It can be concluded that the pressure injection carburetor does not present superior performance over the conventional carburetion systems so far as power output or fuel consumption is concerned. It does, however, permit the engine to idle smoother.

It can also be concluded that the fuel vapor temperature does change while the engine is operating and that the fuel vapor temperature affects the fuel consumption, but that the effect is not serious.

ACKNOWLEDGMENTS

The author wishes to express his appreciation and indebtedness to Professor G. H. Larson for his invaluable direction and assistance in this investigation, to the Minneapolis-Moline Company, the Hercules Motor Corporation, O. L. Garretson of the General Tank and Steel Company, the Tri-County Refrigeration Company, and to the Mechanical Engineering Department for equipment used in these tests.

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THE PERFORMANCE OF LIQUEFIED PETROLEUM GAS CARBURETORS

by

GEORGE MILLARD TURNER

B. S., Oklahoma Agricultural
and Mechanical College, 1948

ABSTRACT

of

A THESIS

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requirements for the degree

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Department of Agricultural Engineering

KANSAS STATE COLLEGE
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INTRODUCTION

LP Gas, an abbreviated term for liquefied petroleum gas, is coming into expanded use in internal combustion engines. In the past this fuel has been wasted by venting it into the atmosphere as a vapor and burning it during the process of producing natural gas and refining crude oil. This process was practiced because there wasno demand for these particular fractions of the natural gas or crude oil which justified the expense and the effort necessary to save the vapors. In order to conserve our natural resources, laws, which prohibit this wasteful practice of flaring, have been passed in recent years by congress.

These vapors are now saved by forcing them into containers or bottles which keep them in the liquid state under moderate pressures. The containers are distributed to consumers beyond the natural gas mains where the fuel is used for the heating of the home, the heating of water, and for cooking just as natural gas is used. In addition to these uses, LP Gas has been accepted as a motor fuel which has been found to be of superior quality to the best gasoline.

At our present rate of petroleum consumption our petroleum supply could be depleted very seriously in the event of a major war. Our agricultural machines and vital transportation vehicles must continue in operation regardless of the state of national affairs. The large-scale utilization of LP Gas as a motor fuel could lessen the demand for gasoline and other petroleum fuels by an amount sufficient to allow a greater use of our petroleum in either war or peace.

There has been such an increasing demand for LP Gas that many manufacturing concerns saw a great possibility for profit in manufacturing equipment designed for the feeding of LP Gas in internal combustion engines. As a result there are several well-known companies manufacturing this equipment and many companies who are unfamiliar to the country as a whole.

OBJECTIVES OF THE INVESTIGATION

The objectives of the investigation were:

1. To compare the performance of the pressure injection carburetor with the conventional carburetors as to:
   a. Maximum power developed
   b. Fuel consumption
   c. Ease of starting
   d. Ease of adjustment
   e. Ease of adapting to engine
2. To determine the effect of the fuel vapor temperature on
   a. Fuel consumption
   b. Air-fuel ratio

TEST EQUIPMENT

A Hercules model OOC, four cylinder, 4" x 4½" engine connected directly to a Detroit hydraulic dynamometer in the agricultural engineering laboratory was used on part of the tests. A Minneapolis-Moline 4 5/8" x 6" engine connected directly to an electric dynamometer in the mechanical engineering laboratory was used on other parts of the tests.

An Electro products exhaust analyzer was used to indicate the air-fuel ratio on each engine. An air box with a 2½" diameter square edge orifice was also used to measure the air flow into the carburetor of the Minneapolis-Moline engine. Copper constantan thermocouples were used to determine the entering air temperature, the fuel vapor temperature, and the mixture temperature.

The Garretson pressure injection system and the Garretson Perma-Balance fuel controller were loaned for use in the investigation. The Minneapolis-Moline engine was equipped with the Ensign carburetion system.

TEST PROCEDURES

Fuel consumption tests were run on each engine with each carburetion system at about ten percent ranges of the maximum power of the engine.

For consideration of the effect of fuel vapor temperature on the air-fuel ratio and fuel consumption the fuel vapor temperature had to be controlled. This was accomplished by a valve in the hot water line going to the fuel vaporizer unit. By throttling the hot water the desired fuel vapor temperature was attained.

SUMMARY OF RESULTS

The first objective, "maximum power developed," was studied by the tests which were run in determining the fuel consumption. Each of the carburetors was adjusted to give maximum power during each of these tests; therefore a comparison can be drawn. In tests on the Minneapolis-Moline engine the Perma-Balance fuel controller allowed the engine to develop slightly more power than the pressure injection system. However, the Ensign system provided the greatest power output of those tested. The corrected maximum power developed with each setup was as follows:

Type of carburetion system	Corrected max. h.p.
Ensign carburetor	62.75
Perma-Balance fuel controller with spud-in carburetor	59.1
Pressure injection carburetor	57.0

As the second objective was "fuel consumption" the results are shown in Fig. 8. The short dash line represents the Ensign system while the long dash line and the solid line represent the Perma-Balance controller system and pressure injection system, respectively. The characteristics of the pressure injection and Perma-Balance controller were similar. These two, however, differ from the Ensign system. The characteristics of each of the systems tested were too rich at part-loads when they were adjusted to give maximum power.

"Ease of starting," the third objective, is usually a question asked about carburetion equipment, especially the LP Gas systems. In that the Hercules engine had to be hand-cranked and the Minneapolis-Moline engine was equipped with a starter a good comparison could be obtained.

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In determining "the effect of the fuel vapor temperature" on the "fuel consumption" it was found that the fuel vapor temperature affects the fuel consumption inversely as the vapor temperature changes. The air-fuel ratio varies directly with changes in the fuel vapor temperature.

Fig. 11 shows the effect of the fuel vapor temperature on the fuel consumption and air-fuel ratio. The upper curve of the air-fuel ratio curves is the measured air-fuel ratio by the air box while the lower is the indicated ratio by Electro products analyzer. One might be led to believe that one or the other is in error; however the work of Paul and Popovich[1] shows that there is about two ratios difference between the measured and indicated ratios. That is about equal to the difference between the two ratio curves of Fig. 11.

Although it was not an objective of the investigation, it was found that the fuel vapor temperature did not greatly affect the mixture temperature, but does tend to directly affect the mixture temperature as can be seen by inspection of the performance data.

It can be concluded that the pressure injection carburetor does not present superior performance over the conventional carburetion systems so far as power output or fuel consumption is concerned. It does, however, permit the engine to idle smoother.

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[1]Paul, W. H., and M. N. Popovich.
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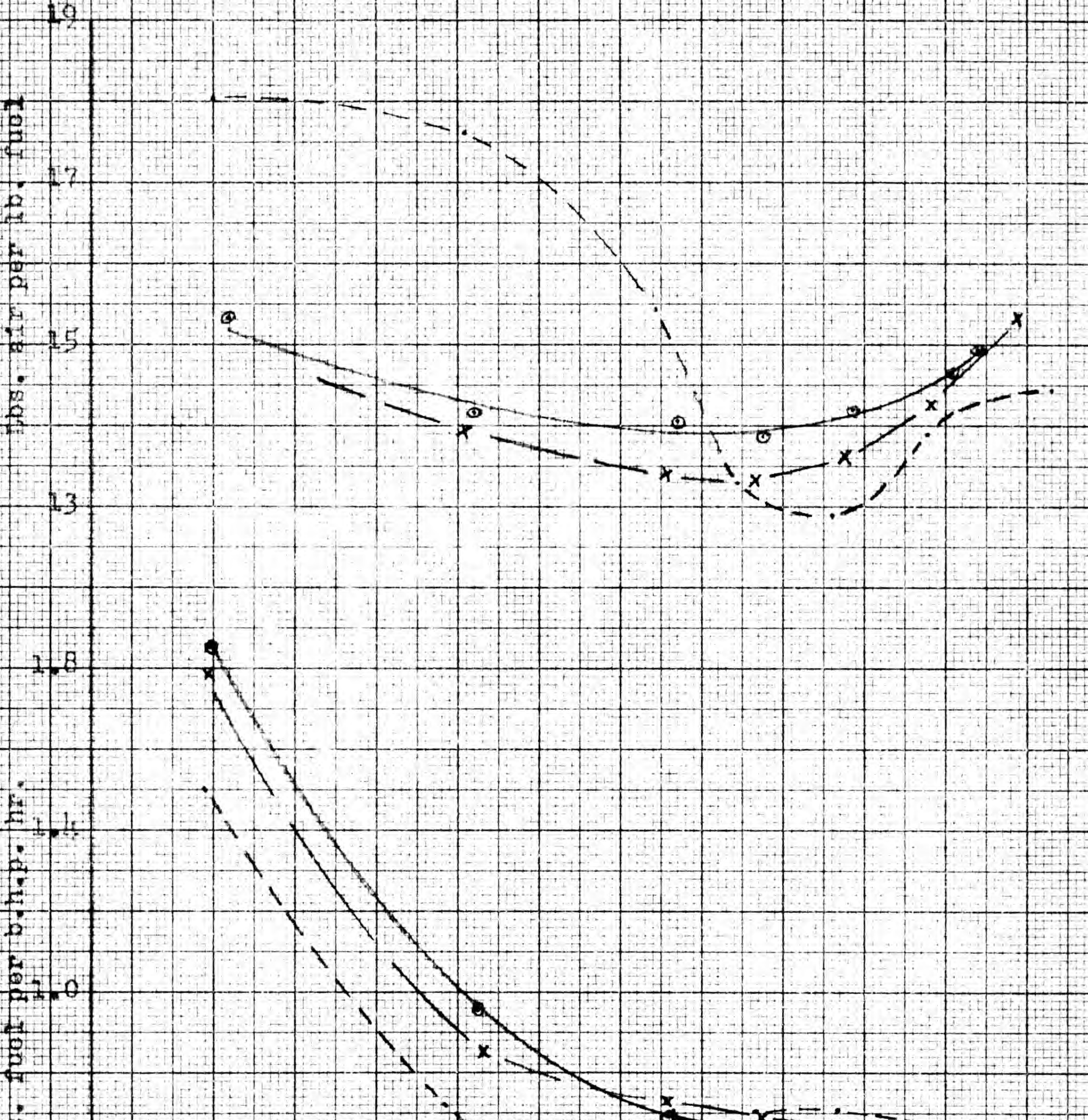

Fig. 8. Specific fuel consumption and measured air-fuel ratio of various carburetion systems - Minneapolis-Moline engine.

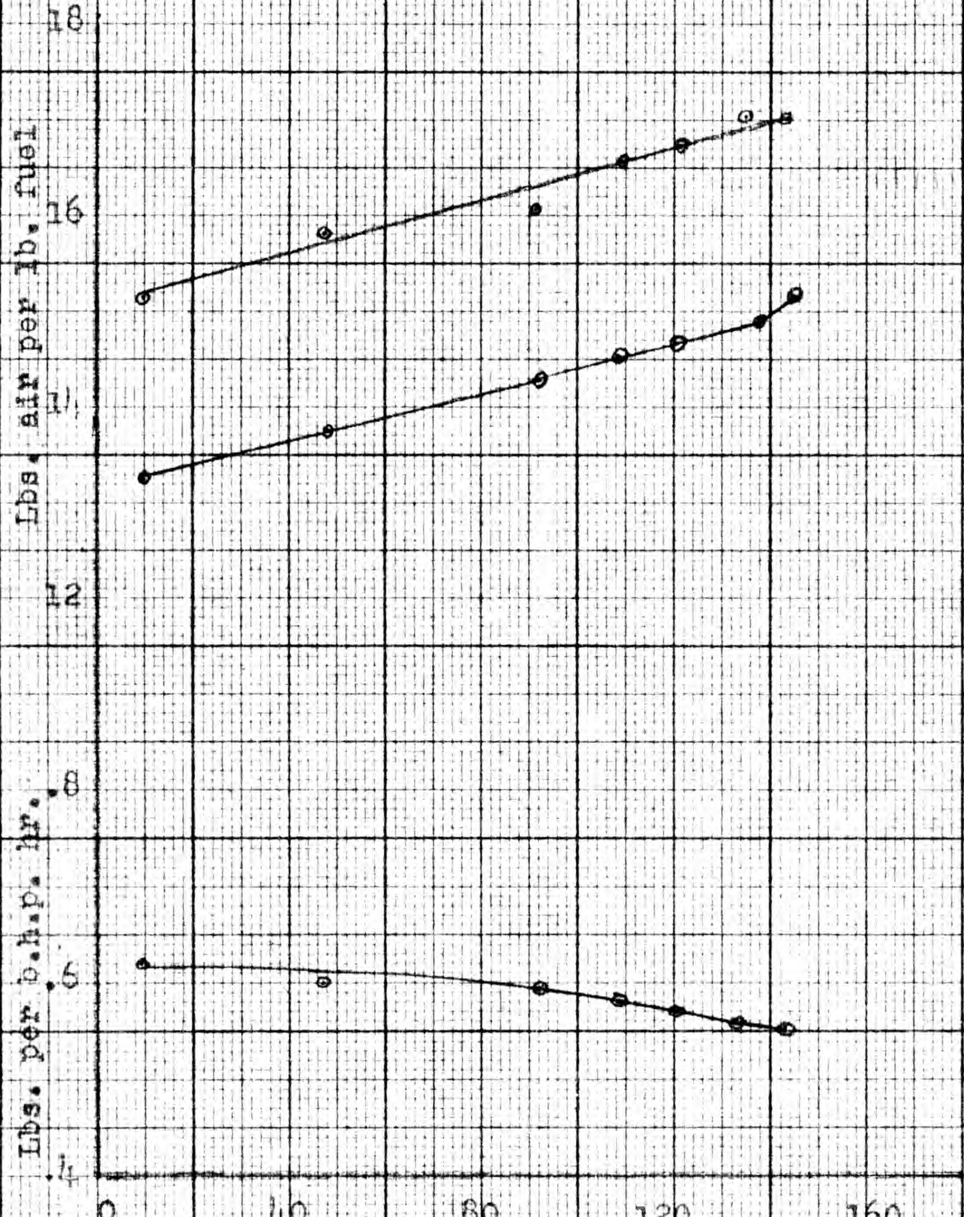

Fig. 11. Effect of fuel vapor temperature on specific fuel consumption and air-fuel ratio - Minneapolis Moline engine at 75 percent of maximum horsepower.