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A REVIEW OF PROPOSED AUTOMOTIVE CARBURETOR CONCEPTS FOR IMPROVED FUEL ECONOMY

M. G. Hinton et al

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16. Abstract

This report presents a brief summarization of available information pertaining to proposed concepts for improved automotive carburetors.

In particular, information is provided which depicts the development and performance characteristics of a selected number of advanced, novel, or new carburetors which have been brought to the attention of the Department of Transportation as having the potential to improve automotive fuel economy. To provide a basis of perspective, a discussion of the basic requirements, construction, method of operating, and inherent limitations of conventional carburetors and induction systems is also included.

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PREFACE

This report was prepared by the staff of the Environmental Programs Group of the Aerospace Corporation, El Segundo, California, for the U.S. Department of Transportation, Transportation Systems Center (TSC). The work was done at the direction of the Mechanical Engineering Division of TSC. It is part of a larger study of fuel economy retrofit devices for highway vehicles being performed by Aerospace under the terms of a reimbursable agreement between the U.S. Air Force and the Department of Transportation. The DOT sponsor is the Office of the Secretary. Work on this study commenced in May 1974.

The report presents the results of a review of proposed concepts for improved automobile carburetion and is based on information acquired and evaluated through July 1974. The emphasis is on devices which have been brought to the attention of the Department of Transportation as having the potential to improve automotive fuel economy.

The report also contains a discussion of the principles of carburetion and fuel induction systems, and general design practices. This information provides a comparative basis for the evaluation of the proposed devices, and indicates the limits of engine improvements attainable through fuel induction system changes.

Of the thirteen devices investigated, the report finds three devices of sufficient merit to be acceptable for further evaluation (i.e., testing). These devices are serious and sophisticated engineering attempts at building a novel carburetor based upon fuel atomization by an ultrasonic generator or the shock wave phenomena associated with supersonic gas flow.

The remaining devices were of limited or no interest. The existing information did not make a reasonable case for the merits of these devices in terms of principle and demonstrated performance.

Future work of the study calls for the testing of the three more promising devices identified in this work.

Appreciation is acknowledged for the guidance and assistance provided by Mr. Michael D. Koplow of the Department of Transportation, Transportation Systems Center, who served as DOT/TSC Technical Monitor for this study.

The following technical personnel of The Aerospace Corporation made valuable contributions to the study:

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1. SUMMARY

The induction system of a conventional gasoline-fueled, spark-ignition automotive engine consists of the carburetor and the intake manifold. The function of the carburetor is to provide the proper air-to-fuel mixture ratio for each engine operating condition, mix the air and fuel as intimately as possible, and regulate the engine power by controlling the air and fuel flow rates. The function of the engine intake manifold is to conduct the wet mixture of air and fuel from the carburetor to all the engine cylinders so that all cylinders receive the same air-fuel ratio. The performance of these functions is complicated by the necessity of accomplishing them over a wide range of engine speeds and vehicle operating modes such as idle, acceleration, steady cruise, cold-starting, warm-up, and wide-open throttle (or maximum power).

In actual practice, conventional carburetor and intake manifolds produce less than ideal fuel atomization and vaporization, result in some maldistribution of fuel-air ratio from cylinder-to-cylinder, and have a practical tolerance band (currently approximately six percent) in air-fuel ratio control accuracy over the operating range. Despite these inherent limitations, conventional carburetors (and intake manifolds) have historically provided an adequate balance of power, driveability, and fuel economy at a minimum cost to the consumer.

The incorporation of emission control techniques (e.g., retarded spark, exhaust gas recirculation, modified shift point logic, reduced compression ratio, and modified valve timing) has reduced vehicle fuel economy. The fuel economy penalty associated with emission controls for the sales-weighted 1973 passenger vehicle fleet was about 10 percent relative to pre-controlled vehicles. A considerable portion of this penalty is associated with (1) rich fuel air mixtures required to offset the reduced vehicle driveability caused by exhaust gas recirculation (EGR), and (2) the nonoptimum spark timing (i.e., late combustion) required to oxidize hydrocarbon (HC) and carbon monoxide (CO) emissions in the exhaust stream.

Thus, there is current interest in carburetion concepts which enable "lean" operation (air-fuel ratios greater than the 16 to 17 range accomplished with conventional carburetion in the cruising mode). The anticipated fuel economy benefit from lean operation for current production engines is estimated at up to 10 percent relative to precontrolled vehicles, and up to 25 to 30 percent for some 1973 and 1974 model year emission control systems, at the respective emission levels of each group.

Further fuel economy gains are potentially available from lean operation, but these cannot be obtained from engines as presently designed. Even with theoretically perfect carburetion, each engine has a mixture ratio which produces minimum fuel consumption for a given power output and engine speed.

This mixture ratio is known as the "equipment lean limit." Going beyond this limit either produces misfire (with unacceptably high emissions) or power loss caused by the excessively long combustion duration of the lean mixture. Clearly, when the "equipment" includes a less than ideal carburetor (i.e., all multicylinder engine carburetors), the equipment lean limit shifts toward richer mixtures.

Design changes to conventional spark ignition engines are yielding better lean mixture performance. However, the compatibility of particular lean mixture engines with present and projected emission standards is an unresolved question. Thus, there is a real possibility that improved carburetors providing better fuel economy will produce unacceptable emissions in retrofit applications.

In addition to carburetor-improvement activities within the auto industry, per se, a number of carburetor or carburetor-like devices have been brought to the attention of the Department of Transportation as having the potential to improve automotive fuel economy. They are shown in Table 1-1, together with a summarization of their operating principles

TABLE 1-1. CARBURETOR DEVICES SUMMARY

Device	Type	System Components	Development Status/ Availability	Relative Suitability for Further Interest and/or Investigation[a]	
Electrosonic Fuel Induction System	Computer-controlled acoustic atomizer	Atomizer, computer, air flow transducer fuel metering pump	Research prototype (120 units)	Acceptable for further evaluation	Potential for lean operation (A/F = 17 to 23). Merits further evaluation, particularly for comparison with cars incorporating EGR for NO_x control. Improved fuel atomization in part throttle and low airflow regime should also be beneficial. Test units should be available.
Ultrasonic Fuel System	Computer-controlled acoustic atomizer	Atomizer, computer fuel metering pump	Research prototype	Acceptable for further evaluation	Similar in concept and benefits to Electrosonic System above. Test unit availability uncertain. One test unit presently on a car.
Kendig Carburetor	Air-valve carburetor	Carburetor only	Development prototype	Limited interest	Available fuel economy data not attractive. Design improvements are currently being made. Manufacturer should provide confirmatory test data before further interest would be warranted. Test units should be available.
Woodworth Carburetor	Air-valve carburetor	Carburetor only	Research prototype	Limited interest	No fuel economy test data available. Somewhat leaner (A/F = 17-18) operation at light cruising loads, fuel cut-off during deceleration, and very fast acting choke should provide some fuel economy benefits. Design improvements are currently being made. Manufacturer should provide confirmatory test data before further interest would be warranted. Test unit should be available.

TABLE 1-1. CARBURETOR DEVICES SUMMARY (Continued)

Device	Type	System Components	Development Status/ Availability	Relative Suitability for Further Interest and/or Investigation[a]	
Arpaia Fuel Injection Carburetor	Air-valve carburetor	Carburetor only	Development prototype	Limited interest	Fuel economy claims not verifiable. Possible benefits may arise from fuel vaporization, faster engine warmup, and leaner operation (A/F = 16-18) during deceleration. Otherwise, operates from rich to stoichiometric (A/F = 14-15). Manufacturer should provide confirmatory test data before further interest would be warranted. Test unit should be available.
Dresserator System	Sonic variable-venturi system	Atomizer, modified intake & exhaust manifolds	Development prototype	Acceptable for further evaluation	Lean operation (A/F = 18-19) potential merits further evaluation, particularly for comparison with cars incorporating EGR for NO_x control. Improved fuel atomization and distribution due to sonic velocity in variable venturi should be beneficial. This system presently being evaluated/developed by Ford. Availability for test by others is uncertain.
Fish Carburetor	Throttle-linked fuel metering carburetor	Carburetor only	In production prior to 1965	Limited interest	Principal attribute would be to improve fuel mixing and distribution on higher displacement engines which normally use carburetors with larger throat diameters. These vehicles would also suffer large power losses at wide-open throttle conditions. Confirmatory test data and engine size class applicability not available. Manufacturer should provide substantiating test data before further interest would be warranted. Test units should be available.

TABLE 1-1. CARBURETOR DEVICES SUMMARY (Continued)

Device	Type	System Components	Development Status/ Availability	Relative Suitability for Further Interest and/or Investigation[a]	
Gelb Digital-Controlled Carburetor	Computer-controlled vaporizer	Vaporizer, computer air flow sensor, fuel metering pump	--	Limited interest	Principal attribute is fuel vaporization to improve mixing and distribution and promote faster warmup. Operates at A/F = 14.6. No test data available. Manufacturer should provide confirmatory test data before further interest is warranted. Test unit availability is unknown.
Pogue Carburetor	Vaporizer	Carburetor only	Experimental unit only	No interest	Carburetor not in existence; none ever manufactured. Concept of fuel vaporization involves complex, high-pressure loss heat exchanger.
Vaporator	Vaporizer	Vaporizer/ separator/ mixer	Research prototype	Limited interest	Fuel vaporization should improve mixing and distribution and enhance engine warmup. Requires heating element for cold start conditions. Adequate confirmatory test data not available. Manufacturer should provide comparative test data before further interest is warranted. An experimental unit should be available for test.
Fessenden Carburetor System	Vaporizer System	Carburetor, blender	Experimental units only	Limited interest	Concept of fuel vaporization should promote improved mixing and distribution as well as faster engine warmup. Presently has no choke which may pose starting problems in cold weather. Adequate confirmatory fuel economy test data not available. Manufacturer should provide substantiating test data before further interest is warranted. An experimental unit should be available for test.

TABLE 1-1. CARBURETOR DEVICES SUMMARY (Concluded)

Device	Type	System Components	Development Status / Availability	Relative Suitability for Further Interest and/or Investigation[a]	
Vapipe	After-carburetor vaporizer	Heat pipe, heat exchanger	Feasibility hardware only	Limited interest	Concept provides fuel vaporization and may add superheat to the fuel-air mixture. Engine power loss accompanies the increased mixture temperature. Available test data which indicates substantial (30-40%) fuel economy improvements over the Federal Driving Cycle may be uniquely related to an induction system having much poorer vaporization characteristics than conventional U.S. passenger cars. Manufacturer should provide further substantiating test data before further interest is warranted. Concept is presently in experimental laboratory hardware and is probably not available for test purposes.
Graybill VMM Injector	Not disclosed	Not disclosed	Research prototype	No Current Interest	Concept originator has released no details of his proposed concept. Until he does, there is no basis for further interest in this concept.

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[a] The relative fuel economy improvement potential of any carburetor depends, of course, on the condition and state-of-tune of the baseline car being compared to.

and characteristics. In general, they embody specific design techniques or approaches which are claimed to overcome one or more of the well-known limitations of conventional carburetors (viz., incomplete atomization or vaporization, maldistribution). Assuming that a given device did in fact improve atomization, vaporization, and maldistribution, fuel economy would not be expected to increase more than a few percent unless the improvements were sufficient to permit operation at "lean" air-fuel ratios as noted previously.

The last column in Table 1-1 provides an indication of the relative current interest in these carburetor concepts for later analysis and/or test evaluations. Three levels of relative ranking are utilized:

a. Acceptable for further evaluation
b. Limited interest
c. No interest

Concepts in the first category (a) are deemed to have sufficiently meritorious operating principles and/or test data to warrant further consideration at this time. Concepts in the second category (b) have operating principles which may indeed improve fuel economy, but which have not been adequately verified by test data or which are too interrelated with specific driving cycle characteristics (e.g., cold starts, hot starts, engine warmup, decelerations, etc.) to permit placing them in category (a) at this time without further substantiating information. Concepts in the third category (c) are those which have no substantiation in operating principle or data, or which do not in fact exist for evaluation purposes.

Nearly all of the carburetor approaches shown in Table 1-1 would be expected, in principle, to allow "lean" operation. Except for the Fish carburetor (which was in limited production a number of years ago), none have passed the development stage. Two of these, the Dresserator carburetor and the Electrosonic Fuel Induction System, are known to have been provided to the auto industry for evaluation.

There is not sufficient available data for any one of the concepts to adequately treat the relationship between fuel economy obtained with the proposed concept carburetor installed and (1) fuel economy of an uncontrolled vehicle or (2) fuel economy of a vehicle controlled to the same emission level afforded by the incorporation of the proposed concept carburetor. Until this type of data is made available, specific fuel economy claims should be viewed with caution.

2. INTRODUCTION

The recent embargo on petroleum exports to the United States by the oil-producing countries of the Middle East has amply demonstrated that automotive fuel shortages in the United States could occur again at any time in the future unless and until the United States becomes self-sufficient with regard to automotive fuel needs. As a result, many concerned people have been postulating various methods for reducing automotive fuel consumption in order to lessen the national demand for petroleum.

In particular, the United States Department of Transportation has been the recipient of many letters and other communications offering or pointing to a number of different carburetion approaches which are claimed to offer significant fuel economy advantages over the standard or conventional carburetor as used in gasoline-fueled spark-ignition engines. In addition to conflicting claims of fuel economy advantages, some of the communicants have expressed the opinion that the automotive industry might be "suppressing" the development or use of such advanced or novel carburetion techniques, in one manner or another.

The present report has been written to respond, at least in part, to those parties interested in fuel economy improvement via carburetion improvements. The purpose of this report is to set forth a "picture of perspective" with which one can rationally judge the relative possible benefits of "new" carburetors.

Thus, the conventional carburetor will first be discussed in terms of how the carburetor is designed, how it works, and what its basic limitations are. Next, current carburetor improvements being developed by the auto industry for near-term implementation will be delineated. Then, a number of selected, specific carburetors currently being produced or discussed in the country will be examined as to their status. This examination will include: principal claimed advantages, principles of operation and construction, available substantive data on fuel economy effects, disadvantages, current development status, costs, etc.

3. THE CONVENTIONAL CARBURETOR

The following discussion very briefly describes the basic requirements, construction, method of operation, and inherent limitations of conventional carburetors and induction systems as used in the vast majority of U.S. passenger cars. (A few imports and high-performance sports cars utilize fuel injection systems; they are not addressed herein). For the reader interested in further details, or in the specifics of the large variety of carburetors in use in this country, References 1 through 3 are recommended reading. For those readers less familiar with automotive engine operation, the first section below is a brief synopsis of spark-ignition engine characteristics.

3.1 BASIC SPARK-IGNITION ENGINE CHARACTERISTICS

Most spark-ignition internal combustion engines used in automobiles today are based on the four-stroke reciprocating-piston principle (shown in Figure 3-1), wherein a piston slides back and forth in a cylinder and transmits power through a simple connecting-rod and crank mechanism to the drive shaft. The four basic strokes (intake, compression, power, and exhaust) and their significant characteristics are depicted and described in Figure 3-1.

Since a spark can ignite only a combustible mixture, a fairly definite and homogenous mixture of fuel and air (termed the "charge") must be present in the combustion chamber if a flame is to be propagated throughout the mixture. When the amounts of fuel and air are present in quantities which provide the precise amount of oxygen to burn all the gasoline present, the mixture is said to be "stoichiometric." When more air (thus more oxygen) is present, the air-fuel ratio is said to be "lean." When less air is present, the air-fuel ratio is said to be "rich."

A carburetor is the usual means for obtaining the desired air-fuel ratio. Figure 3-2 illustrates the basic elements of a simple

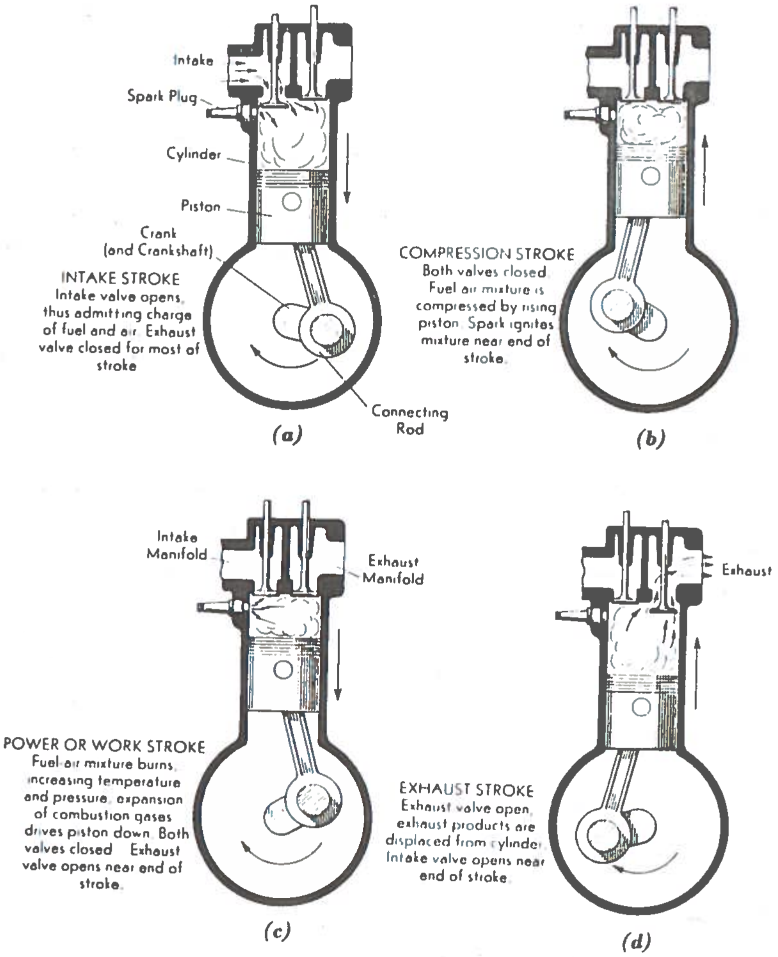

Figure 3-1. The Four-Stroke Spark-Ignition (SI) Cycle (Four strokes of 180 degrees of crankshaft rotation each, or 720 degrees of crankshaft rotation per cycle) (Ref. 1)

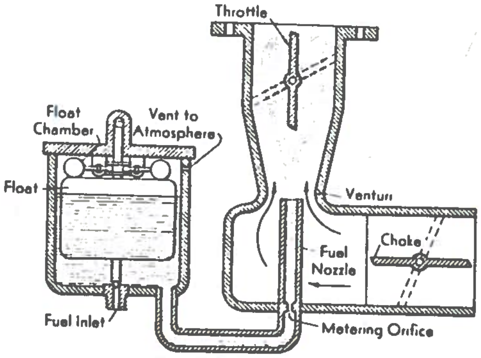

Figure 3-2. Elements of a Simple Updraft Carburetor (Ref. 1)

updraft[1] carburetor: a "venturi," a "fuel nozzle" with "metering orifice," a reservoir of fuel in the "float chamber," a "throttle," and a "choke." Air, at atmospheric pressure, is drawn through the venturi when the piston descends in the intake stroke (see Figure 3-1a). Because of the smaller diameter at the throat of the venturi, the velocity of the air increases at that point and its pressure decreases. Thus the pressure at the tip of the fuel nozzle is less than the pressure (atmospheric) inside the float chamber. Because of this pressure difference, fuel of amount determined by the size of the metering orifice is sprayed into the air stream. If the speed of the engine increases, an increased amount of air is drawn through the venturi and therefore a greater pressure drop is created and a proportionately greater amount of fuel is sprayed into the air stream. Thus, within limits, the carburetor is able to maintain approximately a constant ratio between the air and the fuel throughout the speed range of the engine.

The turning effort applied to the crankshaft depends upon the mass of the mixture burned in each cylinder per cycle and it is controlled by restricting the amount of mixture entering the cylinder on the intake stroke. This is accomplished by using a valve, called the "throttle", on the carburetor to obstruct the passageway into the intake manifold (see Figure 3-2). On the intake stroke, if the throttle is almost closed, only a small amount of mixture will enter the cylinder. When the throttle is gradually opened, the amount of mixture increases and the speed of the engine will increase to a value determined by the external load connected to the drive shaft. Thus the speed of the engine is controlled by the throttle position and, also, by the amount of load. A definite speed can be maintained by varying the throttle position in relation to the load; or the throttle position can be held constant, with the load adjusted to maintain a desired speed.

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[1] The term "updraft" applies when the airflow through the carburetor is from bottom to top, as in Figure 3-2. "Downdraft" infers air flow from top to bottom, as in most present automotive carburetors.

The "choke" enables the engine to receive an additional amount of fuel (a "rich" mixture) for starting when the engine is cold. Closing the choke allows the suction of the engine to be exerted directly on the fuel nozzle while drastically restricting the inflow of air, thus greatly increasing the fuel flow in proportion to the air flow.

3.2 CARBURETOR REQUIREMENTS

The induction system of a conventional gasoline-fueled, spark-ignited automotive engine consists basically of the carburetor and the intake manifold. The function of the carburetor is to provide the proper air-to-fuel mixture ratio for each engine condition, mix the air and fuel as intimately as possible, and provide means for regulating the engine power. The function of the engine intake manifold is to conduct the wet mixture of air and fuel to all the cylinders, in such a manner that all cylinders receive the same air-fuel ratio. Performance of these functions is complicated by the necessity of accomplishing them over a wide range of engine speeds and vehicle operating modes such as idle, acceleration, steady cruise, deceleration, warm-up, and wide-open throttle (or maximum power).

The ratios of air and fuel required for various conditions of speed and load are illustrated in Figure 3-3.

AB	Idling and low-load range (throttle almost closed)
BC	Economy (cruise) or medium-load range (throttle partially open)
DE	Power or full-load range (throttle wide open, WOT)

3.2.1 Idling and Low Load

During idling and low load the engine throttle valve is near the closed position, and the engine requires a rich mixture as shown by line AB in Figure 3-3. Under these conditions the pressure in the intake manifold is far below atmospheric, while the pressure at the end of the exhaust stroke is always close to atmospheric. When the intake valve opens, a higher

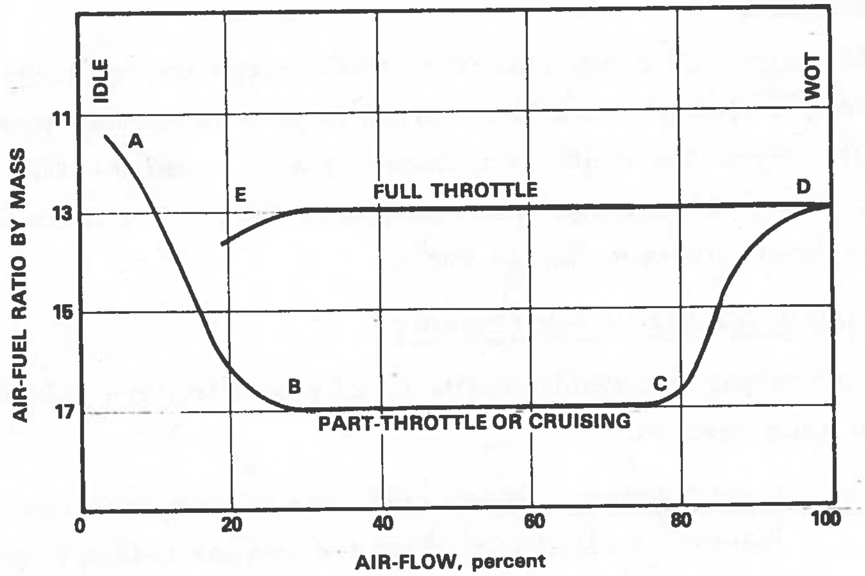


Figure 3-3. Air-Fuel Ratio Required by a Spark-Ignition Engine at Various Air Flow Rates (Ref. 2)

pressure exists in the cylinder than in the intake manifold, and the relatively high-pressure exhaust gas expands into the intake manifold. Later, the exhaust gases are drawn back into the cylinder on the intake stroke along with a portion of the fresh charge, resulting in an overall mixture containing a high percentage of exhaust gases. A very rich mixture is required to ensure proper combustion of the diluted charge. The dilution is maximum under no-load conditions and is gradually reduced with an increase in load or throttle valve opening.

3.2.2 Medium Loads or Cruise

Under these load conditions the throttle opening is sufficiently large that the effect of dilution is negligible, and a lean mixture is used to provide optimum fuel economy (see line BC in Figure 3-3). An air-fuel ratio (A/F) of approximately 16 to 17 is the best compromise for the various possible part load requirements of a modern spark-ignition engine.

3.2.3 High Loads

Under high load conditions when the throttle valve is opened 75 percent or greater, a rich mixture is required to give maximum power (line CD in Figure 3-3). When the speed is reduced at wide-open throttle (WOT) by increasing the load, the air-fuel ratio requirement passes from D to E (Figure 3-3), ideally at constant charge ratio.

3.2.4 Transient Mixture Requirements

The principal transient conditions of operation are cold starting, warm up, and acceleration.

a. Cold Starting. When cold, the engine requires a very rich mixture so that sufficient fuel-vapor exists to produce a combustible mixture (a fuel-air ratio of 1:1 may be required). This very rich mixture is obtained by the use of a choke valve.

b. Warm Up. During engine warm-up, a rich fuel-air ratio is required, but the degree of richness must be progressively reduced during the warm-up period.

c. Acceleration. During acceleration, the throttle valve is suddenly opened and the intake manifold pressure is increased. Unless some supplementary fuel is added to the mixture, a momentary lean condition will result, arising from both the inertia of the liquid fuel in the manifold and the decrease in evaporation of the fuel at the higher manifold pressure. An acceleration pump is used to provide this additional fuel.

3.3 CARBURETOR CONSTRUCTION AND OPERATION

All of the basic elements of a single-barrel carburetor (or of a primary barrel of a multi-barrel carburetor) are illustrated in Figure 3-4.

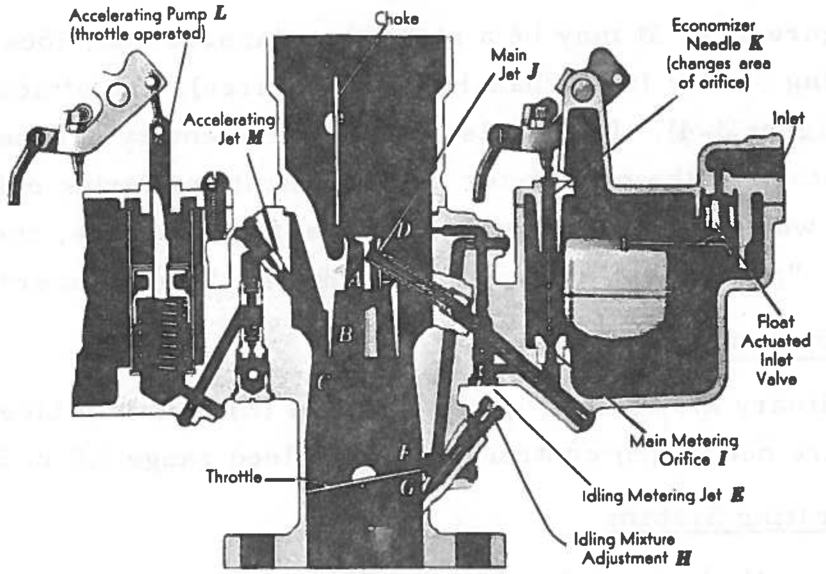


Figure 3-4. Carter Downdraft Triple-Venturi Carburetor with High-load Enriching Device (Ref. 1)

3.3.1 Main Metering System

A triple venturi (A, B, C) is the means of obtaining a relatively high vacuum on the main jet (J) at relatively low air flow. With two or more venturis in series, only a fraction of the air experiences the maximum venturi depression and therefore the overall pressure loss is reduced. Also, the fuel is well atomized in the smaller venturi and then this air and fuel mixture is discharged centrally in the succeeding venturi, leading to a more homogeneous mixture.

The "main jet" or "discharge tube" or "nozzle" (J) is a fairly large (relative to the metering orifice, I) tube, with its tip at or near the throat of the venturi.

The main metering orifice (I) controls the economy or cruise range fuel requirements (line BC in Figure 3-3).

The "economizer" is a supplementary metering orifice and its actuator, located in the main metering system, which controls the power range DE in Figure 3-3. It may be a stepped or tapered rod, located within the main metering orifice (thus changing the flow area), and attached to the throttle (K in Figure 3-4). It may also be a supplementary orifice actuated by a vacuum piston. If the carburetor has a separate metering orifice and a separate nozzle which go into operation at or near full throttle, the arrangement is called a "power-jet" system rather than an "economizer" system.

3.3.2 Idling System

The primary air bleed (D), metering jet (E), off-idle bleeds (F, G), and idling mixture needle (H) control the idling bleed range AB of Figure 3-3.

3.3.3 Accelerating System

If the throttle is opened suddenly, the air response is nearly instantaneous, but the fuel flow lags because of fluid friction enhanced by the long passageways to the float bowl. To supply additional fuel, a piston-type pump is actuated either by the throttle linkage (L) or by a vacuum operated piston.

3.3.4 Operational Characteristics

Performance tests (air box) of a commercial carburetor at part- and full-throttle are shown in Figure 3-5. Thus, in the performance tests of real carburetors, deviations are apparent from the ideal requirements of Figure 3-3.

3.4 INHERENT LIMITATIONS

Ideally, the air-fuel mixture reaching the combustion chambers should be uniform from cycle to cycle and from cylinder to cylinder, and the fuel should be largely vaporized or finely atomized and uniformly mixed in the air stream. Real systems fail to achieve this ideal and the cylinders receive air, vaporized fuel, atomized particles and droplets of liquid fuel, and (at part throttle) a liberal amount of exhaust residual. This departure from ideal conditions affects power, driveability, and fuel economy.

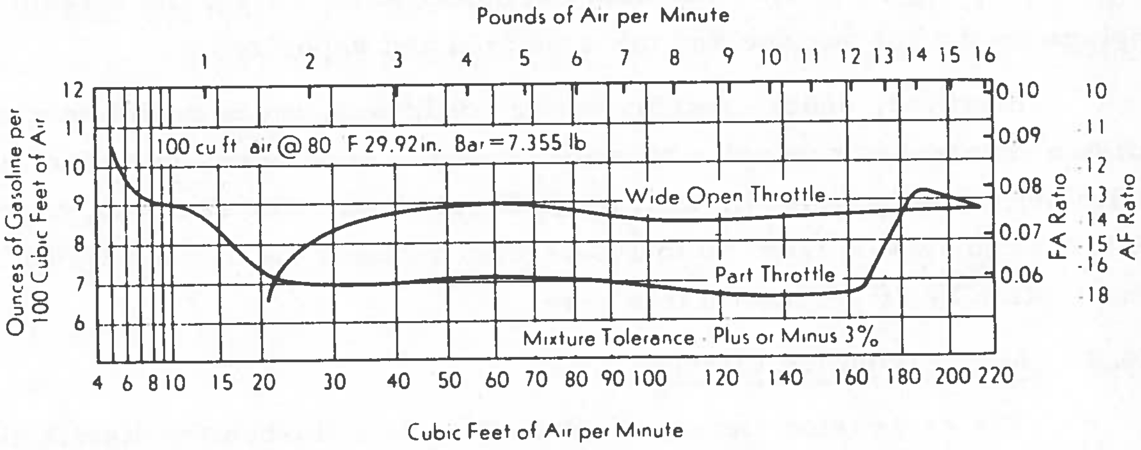


Figure 3-5. Performance Test of Chrysler Corporation Carburetor (Ref. 1)

3.4.1 Atomization and Vaporization

Conventional venturi-type atomizers are capable of producing desired levels of atomization only at the high venturi air velocities obtained at high engine power levels. Directly at the jet of the carburetor, the ratio of the mass of air to the mass of vaporized fuel is high, but as the mixture travels through the manifold, vaporization increases (heat is supplied), and the ratio of the mass of air to the mass of vaporized fuel falls. Since the work of an engine is directly dependent on the mass of air inducted, complete vaporization of the fuel is not normally desired as the vaporized fuel would displace air and reduce power output. On the other hand, too little vaporization in the manifold may lead to poor distribution of the fuel from cylinder to cylinder; although the carburetor delivers a fixed air-fuel ratio, the air fuel ratio may vary greatly from cylinder to cylinder. A figure of 60-percent vaporization in the manifold at wide-open throttle is generally selected as a reasonable value for acceptable distribution and good power output capability. Normally, heat for fuel vaporization is supplied through a "hot spot" located directly beneath the throttle (see Figure 3-7). The heavy droplets of fuel in the air stream impinge on the hot surface and are atomized and vaporized.

However, under cruising power conditions, more complete vaporization of the fuel is conducive to higher thermal efficiency (lower fuel consumption), as illustrated by the data in Figure 3-6. For example, increasing the fuel vaporization from 60 to 100 percent reduced the brake specific fuel consumption by 16 percent in this case.

3.4.2 Maldistribution Effects

The carburetor and manifold profoundly influence the distribution of fuel to the cylinders. One cause is the throttle plate which, at part throttle, diverts the flow from the nozzle towards the wall of the manifold (Figure 3-7). In addition, flow passing the throttle plate sets up a low-pressure region on the underside of the trailing edge, tending to deflect fuel

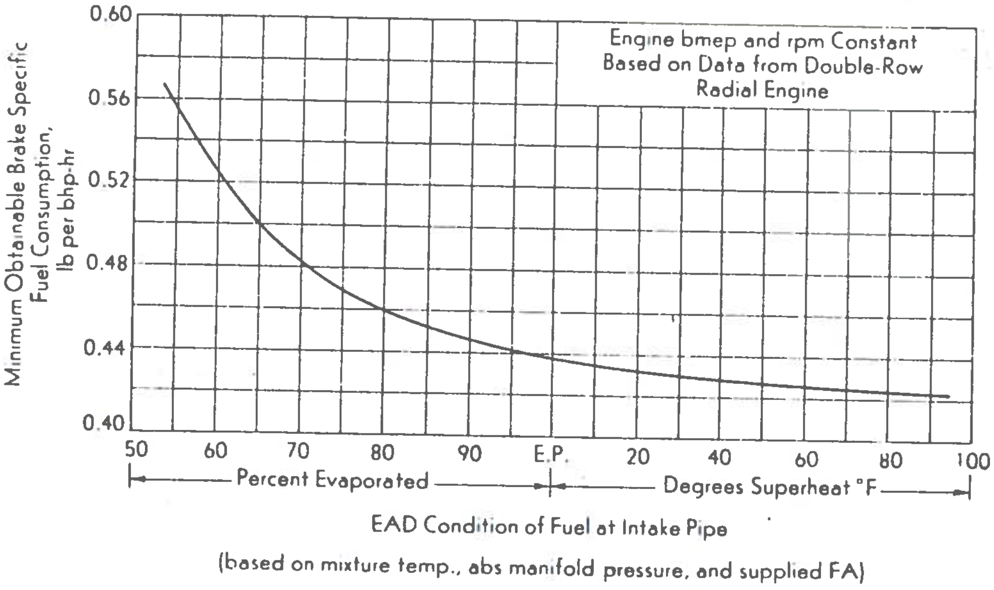


Figure 3-6. Example of Typical Correlation of Minimum Obtainable bsfc with Equilibrium Air Distillation of Fuel (Curve shown is typical of that found with large radial engines under cruising-power conditions, but is greatly influenced by engine design and operating conditions) (Ref. 1)

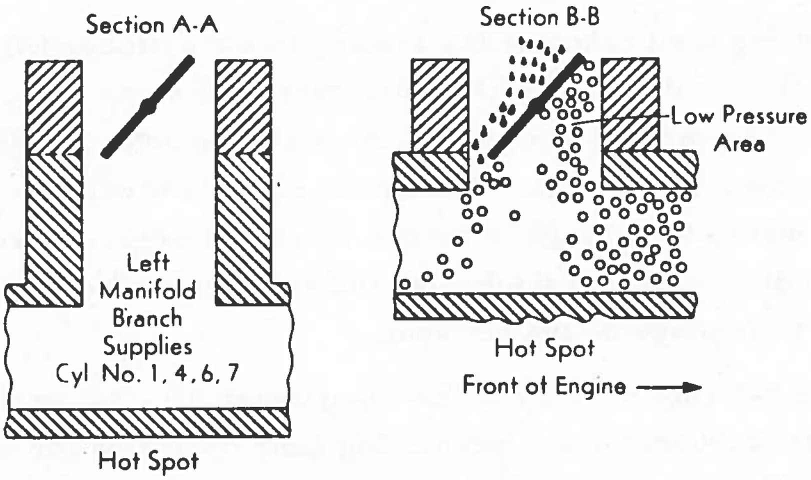
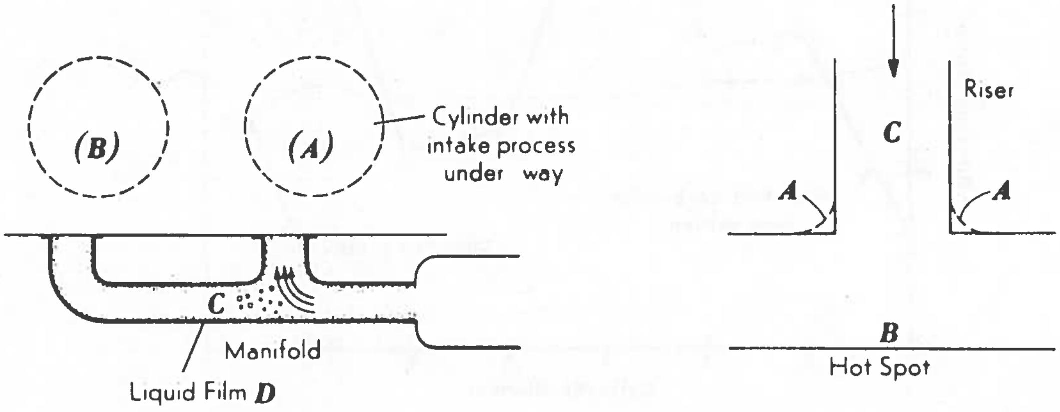


Figure 3-7. Cross Sections through Intake Manifold of V-8 Engines (Showing different heights of risers, and throttle in worst position for distribution) (Ref. 1)

towards the front cylinders (as shown). Slight changes in the position of any carburetor component (in particular, the throttle and choke) in the air stream can markedly change the distribution patterns.

In the case of the intake manifold (see Figure 3-8a), the inertia of heavy liquid droplets (C) in the header may prevent them from turning the



(a) Division at a port (b) Division at the Riser hot spot

Figure 3-8. Fuel Flow in Manifold (Ref. 1) corner and entering the branch or leg leading to the cylinder (A). Also, the fuel flowing on the manifold wall (D) experiences the same difficulty (which can be minimized by smooth surfaces). As a consequence the end cylinder (B) receives an overrich charge. The inverse problem exists at the riser (Figure 3-8b), where the charge descends into the header. Here the sharp 90-degree bend discourages a thick film and streamline flow and aids the drops and film to impinge on the hot spot.

Figure 3-9 shows the cylinder-to-cylinder air-fuel variations for both conventional carburetor and vaporizing tank operation for an eight-cylinder engine operating at the 30-mile-per-hour cruise mode. Maldistribution is almost completely eliminated when the fuel is completely vaporized and completely mixed before entering the inlet manifold. The maximum air-fuel ratio spread with carburetor operation was 2.3. At other vehicle operating modes the air-fuel ratio spread varied from 1.3 to 2.0 with the carburetor, and from 0.3 to 0.7 with vaporizing tank operation (Ref. 4).

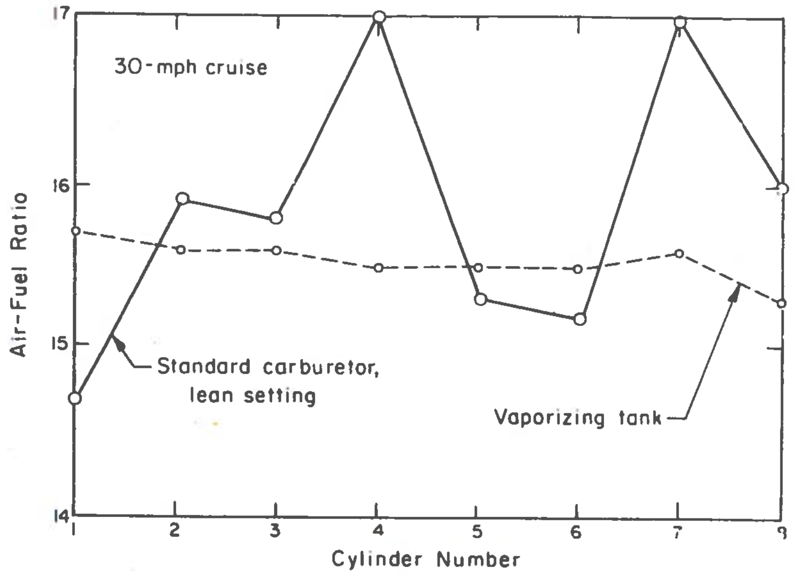


Figure 3-9. Geometric Distribution of Air-Fuel Ratio for Carbureted and Vaporized Fuel in an 8-Cylinder Engine (Ref. 4)

Similar data for a 6-cylinder engine is shown in Figure 3-10. Geometric maldistribution is poor at wide open throttle with standard carburetion, but fairly good at part throttle (road load). Distribution with vaporized and premixed fuel is good at all operating conditions.

Figures 3-11 and 3-12 present the variation of indicated specific fuel consumption (ISFC) versus air-fuel ratio for the geometric maldistribution with the two types of carburetion shown in Figure 3-10 (1200 and 2400 rpm cases shown in addition to 1600 rpm case). In this engine test series there did not appear to be significant differences between standard carburetion and vaporizing tank operation. However, there is a broader range of air-fuel ratios where vaporization tank carburetion gives near minimum specific fuel consumption. This broader range could simplify fuel metering for maximum economy (Ref. 6). These data (Figures 3-11 and 3-12) are for one engine

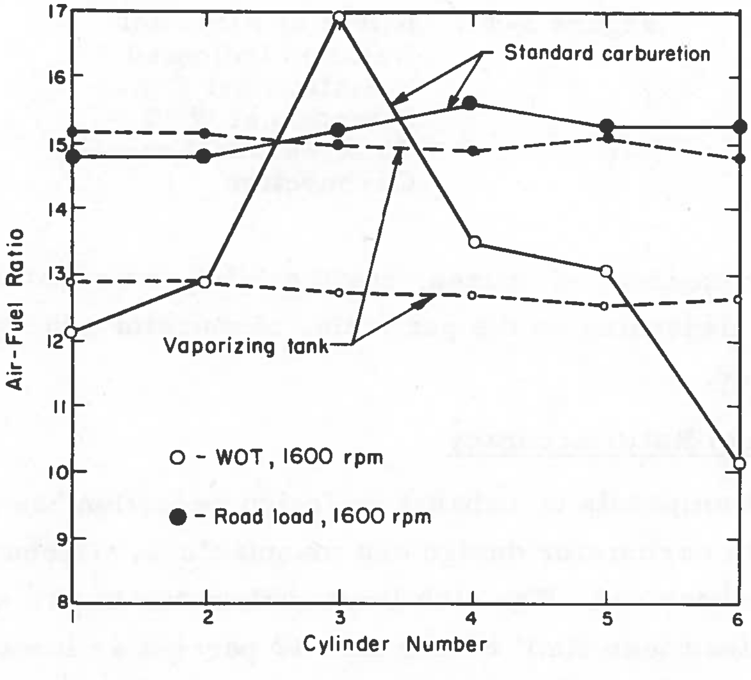


Figure 3-10. Geometric Distribution of Air-Fuel Ratio for Carbureted and Vaporized Fuel in a 6-Cylinder Engine (Ref. 4)

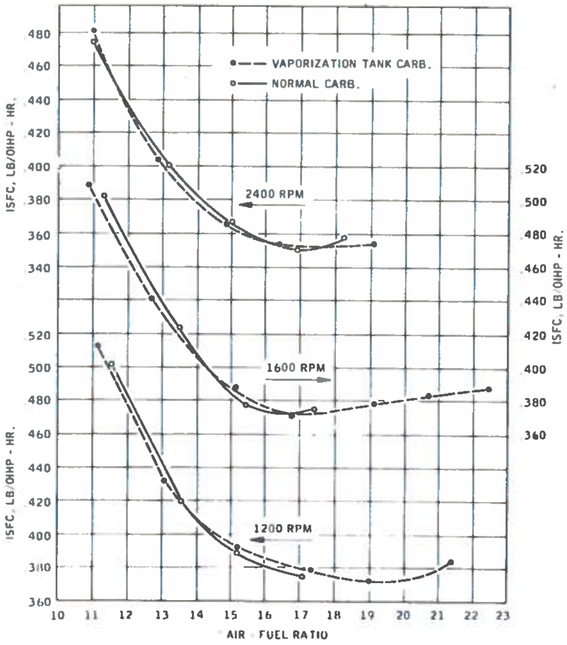


Figure 3-11. Effect of Air-Fuel Ratio on Indicated Specific Fuel Consumption at WOT — Tank Versus Normal Carburetion

only. Different engines, of course, could exhibit somewhat different characteristics depending on the particular carburetor and intake manifold designs employed.

3.4.3 Air-Fuel Ratio Accuracy

Recent emphasis on exhaust emission reduction has resulted in improvements in carburetor design and manufacture. Carburetor tolerances have been cut. The rich limit carburetor is now set only six percent richer than lean limit rather than 12 percent as it was formerly. Each carburetor is checked on a flow stand and an adjustment is made to control the off-idle mixture ratio. Finally, the idle adjustment itself has been limited so that excessively rich mixtures at idle cannot be obtained.

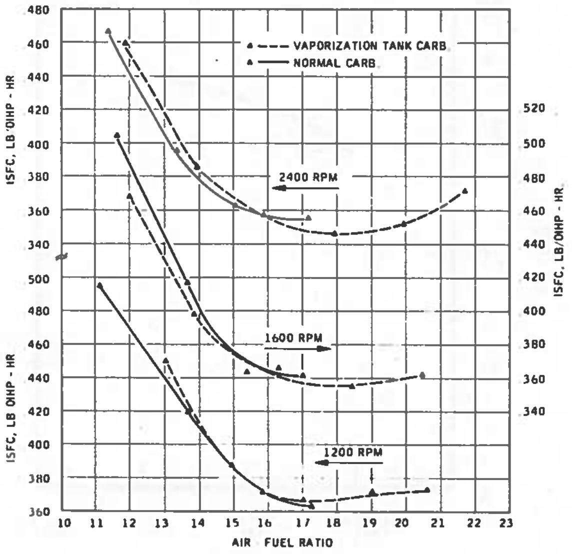


Figure 3-12. Effect of Air-Fuel Ratio on Indicated Specific Fuel Consumption at Road Load — Tank Versus Normal Carburetion (Ref. 6)

3.4.4 Lean Air-Fuel Ratio Effects and Limits

As illustrated in Figure 3-13, the engine indicated thermal efficiency[2] increases as the air-fuel ratio increases, or as the mixture becomes leaner. This results because an increased quantity of air decreases the temperature rise during the combustion process; however, the temperature and pressure rise (and thus work) per unit of fuel energy supplied are increased because the specific heats are lower at lower temperatures. Conversely, if excess fuel is present, it does not increase the work in proportion to the increase in fuel and the efficiency decreases as the mixture is made richer. Since specific fuel consumption is inversely proportional to thermal efficiency, fuel

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[2] Thermal efficiency is the fraction of the heat energy supplied that is converted into work.

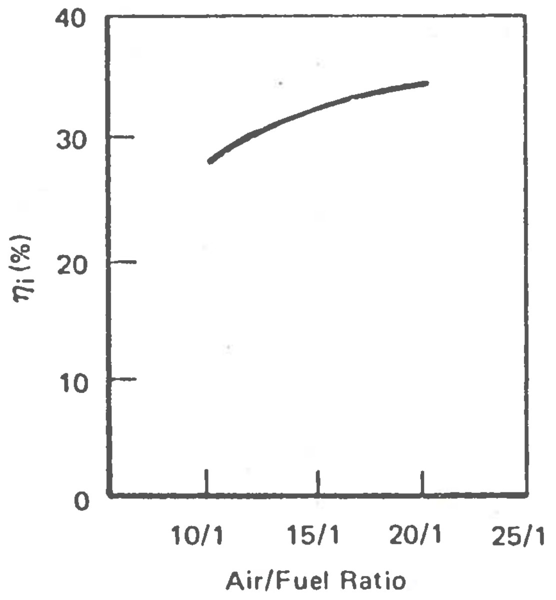

Figure 3-13. Effect of Air-Fuel Ratio on Indicated Thermal Efficiency at Fixed Compression Ratio (Example Only)

consumption decreases as the air-fuel ratio increases until the lean misfire limit is reached or until the mixture flame speed is so low that the ignition spark timing cannot be advanced sufficiently to assure complete combustion.

This effect is illustrated in Figure 3-14 for a six-cylinder engine. The best economy was obtained at a lean air-fuel ratio of 16.4. From this value up to the lean misfire limit (air-fuel ratio = 21.5) the brake specific fuel consumption increased because of the long period of combustion resulting from slow flame speeds at the very lean mixtures. However, in tests of another four-cylinder engine (Figure 3-14), the specific fuel consumption continued to decrease up to air-fuel ratios of 20. Of course, specific fuel consumption values at fixed steady-state conditions (such as shown in Figure 3-14) do not bear a one-to-one correlation with vehicle fuel economy as measured in miles per gallon. They do, however, provide indicative trends and approximations of fuel economy changes at the given test condition.

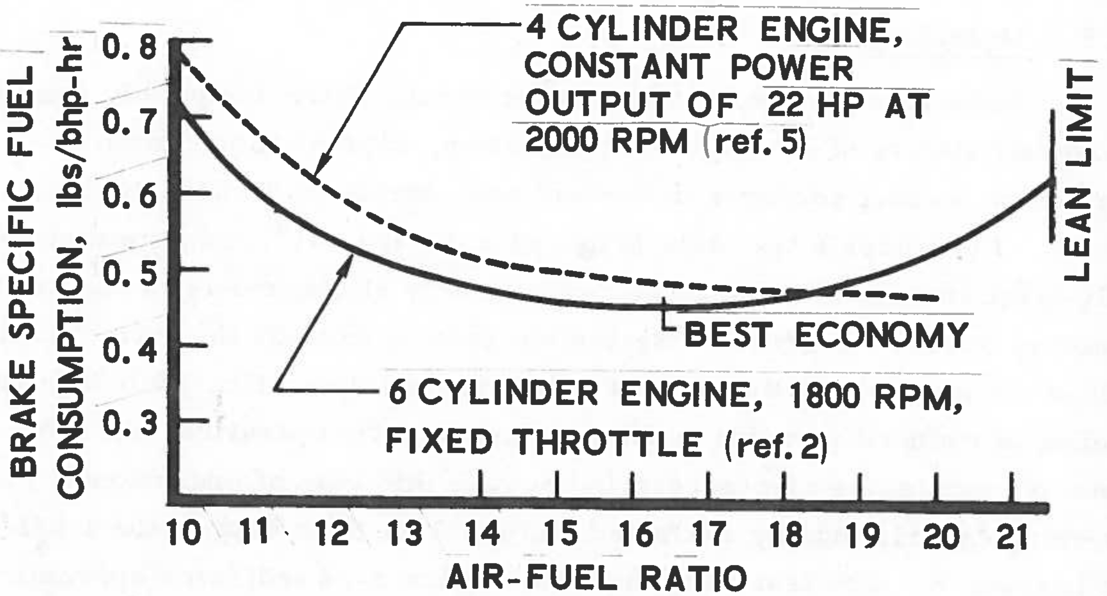

Figure 3-14. Effect of Air-Fuel Ratio on Specific Fuel Consumption

Because of its potential in reducing exhaust emissions and at the same time increasing automotive fuel economy, a great many methods have been proposed to obtain "lean-mixture" operation (air-fuel mixtures leaner than those normally used in carbureted engines). In the fuel system area, these include heated intake air, fuel vaporizing or dispersing devices, etc. As noted earlier, lean operation reduces the specific power output at a given throttle setting; however, at part load conditions a wider throttle opening can be used to obtain the desired power at the leaner mixture with a concomitant reduction in induction system pumping losses. These pumping losses represent the pressure drops experienced by the air in passing through the restrictions of the air cleaner, carburetor body, throttle valve, and inlet manifold. Since the throttle valve pressure drop is reduced by opening the throttle (less restriction), the requirement for a wider throttle opening with lean operation at a given power output thus can reduce the overall induction system pumping losses.

3.4.5 Overall Effects

Unfortunately there is little direct data which adequately quantifies the overall effects of incomplete atomization, vaporization, and maldistribution on fuel economy in conventional carbureted spark-ignition engines. Reference 6 test data (Figures 3-11 and 3-12) indicate that relatively large maldistribution of fuel causes only slight losses in engine fuel economy, but that improved distribution greatly extends the lean operating limit of the engine. In the case of lean-mixture operation, including the benefits of reduced pumping losses at part throttle operation, the fuel economy results are also uncertain because this type of operation is just now being experimentally evaluated and there is little data in the available literature. The test data shown in Figure 3-14 indicates approximately a six-percent improvement in operating at an air-fuel ratio of 20 instead of 15. Schweitzer (Ref. 7) indicates a postulated improvement of seven percent in fuel economy by operating at an air-fuel ratio of 22 instead of 15. However, as compared with emission controlled vehicles operating with rich mixtures, estimates of fuel economy improvements (at the same emission levels) for lean-mixture operation range up to 30 percent (Ref. 7).

4. CURRENT CARBURETOR IMPROVEMENTS

At the present time, the automotive industry is engaged in carburetor modifications or improvements that are directly related to exhaust emission control systems. Such carburetor/intake system modifications are generally directed toward improving the precision and stability of air-fuel ratio control and also include such features as altitude compensation, quick-release choke devices, and intake manifold heating.

Also, at least some auto manufacturers are actively investigating and evaluating carburetor concepts which enable very lean operation (air-fuel ratio >20) for control of oxides of nitrogen, in combination with the potential for fuel economy improvement. In addition to their in-house carburetor developments, the auto manufacturers are examining the concepts of others. For example, the Ford Motor Company is evaluating the Dresserator carubretor and prototypes of the Electrosonic Fuel Induction System have been submitted to the auto companies for test and evaluation. Thus the automotive industry either has evaluated or is in the process of evaluating several of the "new" carburetor systems discussed below.

5. STATUS OF OTHER PUBLICIZED CARBURETORS

5.1 INTRODUCTION

The following sections briefly delineate the available descriptive information pertaining to a number of selected, specific carburetors. These carburetors or carburetor-like devices were either brought directly to the attention of the U. S. Department of Transportation by an interested party or were "discovered" in the present study through news articles, press releases, or private discussions. In all cases, specific claims of fuel economy improvement are made for these carburetors.

Items treated are: principles of construction and operation, principal claimed advantages, available fuel economy data, possible disadvantages, current development status, and costs. However, in some cases, the information is quite limited due to the lack of data or the inability to obtain information from the concept originator or promoter.

In particular, attention is drawn to the fact that in all cases it is not possible to define, with any degree of accuracy, the relative magnitude of fuel economy improvement claimed over a reasonable baseline or standard case. In some cases no test data is available. In other cases, claimed test results are given but there is no definition of the test procedure or duty cycle used and no indication of the state-of-tune or other condition of the test car prior to the incorporation of a given concept. Obviously, if a given vehicle were malfunctioning in some manner during a baseline test, the addition of a different carburetor might result in substantial fuel economy improvements over the initial degraded performance of the vehicle. In most cases, it would be expected that the proposed concept carburetors installed in the test vehicles were carefully calibrated and adjusted to maximize the performance of that specific carburetor-vehicle combination. This aspect also applies to cases where the baseline test car incorporated emission control components which degraded fuel economy. Here any percentage fuel improvements reported would relate only to the vehicle in its emission controlled state and not to that vehicle with a different degree of emission control.

There is not sufficient data for any one of the following concepts to adequately treat the relationship between fuel economy obtained with the proposed concept carburetor installed and (1) fuel economy of an uncontrolled vehicle, or (2) fuel economy of a vehicle controlled to the same emission level afforded by the incorporation of the proposed concept carburetor. Therefore, the fuel economy data or claims presented in the following sections should be viewed with these cautionary remarks in mind.

5.2 ELECTROSONIC FUEL INDUCTION SYSTEM

The Electrosonic Fuel Induction System is a development of Autotronics Control Corporation, El Paso, Texas. It is a computer-controlled, fuel-induction system designed to deliver a preset, lean, air-fuel mixture to the engine over a range of vehicle operating conditions.

The system incorporates four principal components: an air flow transducer, a fuel metering pump, an ultrasonic atomizing and fuel mixing chamber, and a fuel flow computer-controller (see Figure 5-1). The atomizing and mixing chamber replaces the conventional carburetor. Engine power is modulated by means of a conventional accelerator-pedal linkage which operates an air-control butterfly valve or throttle at the intake of the mixing chamber. The inducted air is measured volumetrically by a turbine flowmeter. This, together with sensed pressure and temperature, generates computer input signals which establish the mass flow of the intake air. Fuel flow is computer-derived and controlled in proper relation to the measured air flow so as to maintain a preset (nominal) air-fuel mixture. Metered fuel is delivered to the atomizing and mixing chamber by a positive displacement pump which also provides a tachometer output to the computer-controller for closed-loop pump revolutions-per-minute (rpm) control.

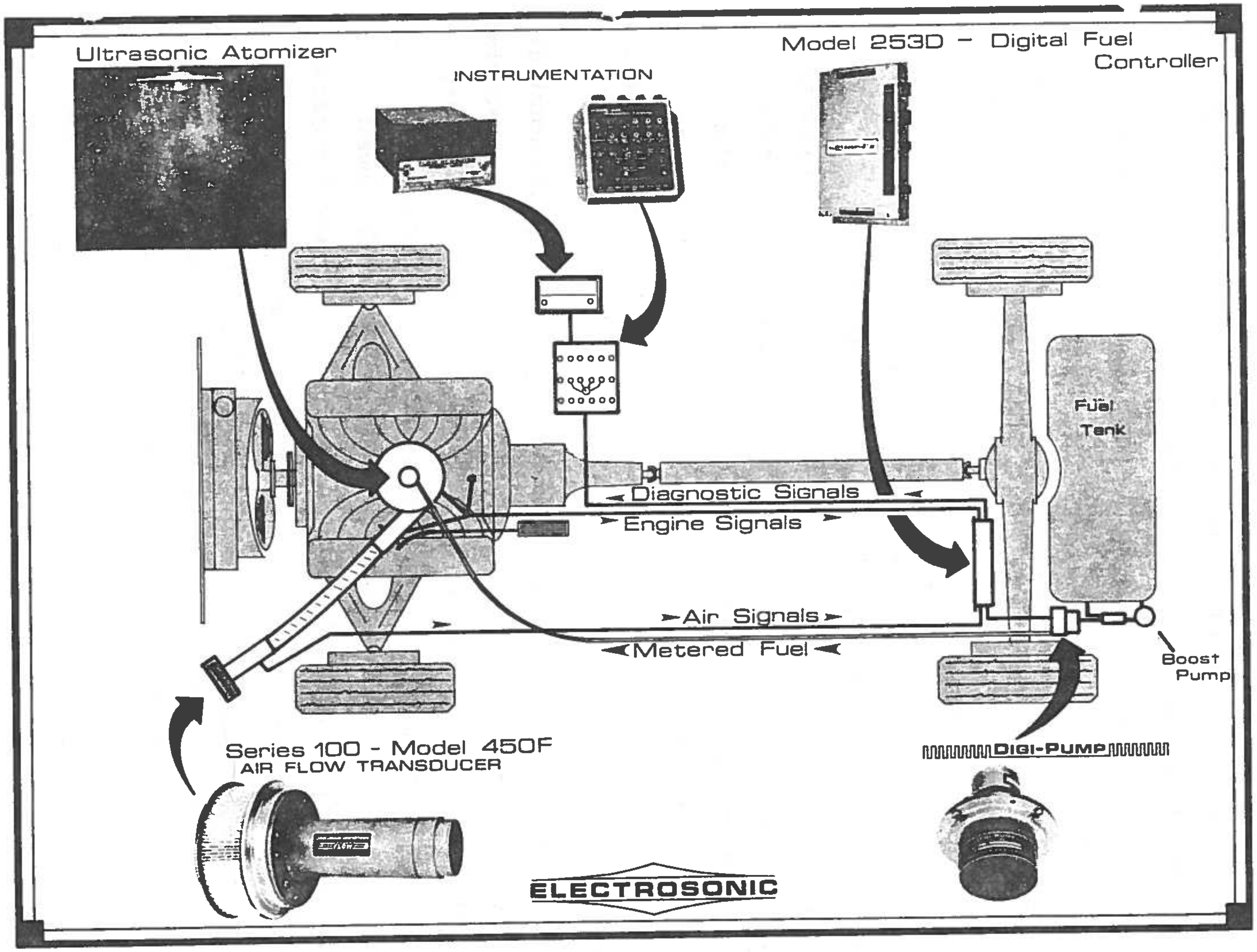

Figure 5-1. Electrosonic Fuel Induction System (Ref. 11)

The system provides for mixture enrichment under warmup, idle, and acceleration conditions as sensed by various engine signals. There are two stages of acceleration enrichment that are activated in response to two levels of manifold pressure and engine rpm inputs. In addition, an idle enrichment setting activated by a threshold level of intake air flow provides an enriched mixture which is modulated in response to manifold temperature changes during warmup operations.

The function of the ultrasonic atomizing device is to produce a fine spray of small fuel droplets, which the manufacturer suggests assists in achieving a better mixture of air and fuel, thereby improving combustion efficiency and engine operating performance at extremely lean mixtures where engine emissions are minimized. A substantial improvement in fuel economy associated with the atomizing action at lean mixtures is claimed: 20 to 25 percent (Ref. 8), but substantiating data is lacking.

The device has been tested on a number of cars, with nominal air-fuel settings ranging from 17 to 23. The vehicles tested were reported to run smoothly except at the lean limit of this range where driveability became noticeably poorer. One system installed in a 1973 Plymouth Fury 360 V8 was emission-tested at Olsen Laboratories by Rockwell International, Inc. This system incorporated a multiple spark discharge ignition device and was equipped with a pneumatic version of the fuel atomizer. The system was run at an air-fuel setting of 17 as recommended by the manufacturer for minimum emissions. No fuel economy tests were run (Ref. 9) and the following emission results were obtained.

1975 CVS Emission Test Results, g/mi

	HC	CO	NO_x
Without Device	1.0	12.7	2.1
With Device	0.6	7.7	3.5
Original 1975 Standards	0.41	3.4	3.1
Interim 1975 Standards			
Federal	1.5	15.0	3.1
California	0.9	9.0	2.0

The manufacturer's claims or expectations regarding the fuel economy benefits of this system are evidently based on the postulate that specific fuel consumption will optimize at ultra-lean mixtures if the borderline of incipient misfire is extended toward the flammability limit of the fuel by better mixing and distribution of the air-fuel charge. While improved mixture quality has been shown to be advantageous in extending the lean limit of engine combustion (Ref. 10), evidence supporting the possibility of substantial fuel economy gains by this approach has not been developed. The manufacturer reports that the system was tested in a number of vehicles (including a Chrysler product, two General Motors cars, and two Fords), with fuel economy improvements of 22 to 28 percent being achieved. However, details of the test duty cycle used, etc., were not reported (Ref. 11).

One obvious disadvantage of the system is its relative complexity; this may create maintenance problems and add to the cost of owner operation. The manufacturer regards the device primarily as a Manufacturer's original equipment (OEM) product which would add about $50 to the purchase price of the automobile. This estimate is based on the assumption that the system would eliminate the need for all other new car emission control equipment.

Less than 150 units of the Electrosonic system have been produced. The manufacturing cost of the unit produced in large quantities was estimated by the manufacturer to be $60. At present, the manufacturer considers the device to be a research tool and does not plan to proceed with the manufacturing development of the system at this time (Ref. 11).

In summary, the claims made for this system appear to be based on benefits of lean operation and improved combustion as derived from better atomization, mixing, and distribution of the fuel charge. Test evidence supporting the manufacturer's claim of a 20- to 25-percent improvement in fuel economy is lacking. Data from other sources indicate that the benefits of lean operation at 19 to 1 air-fuel ratio are less than four percent relative to a baseline system operating at 16 to 1 air-fuel ratio, while the gains derivable from better mixing of the fuel charge by atomization or vaporization may be only a few percent relative to the performance provided by conventional carburetors and intake manifolds at steady-state cruise conditions. Some consideration may be given to the system's development potential as a device for achieving emission control through ultra-lean operation with non-negative fuel economy effects and with minimum penalty on vehicle driveability. However, complexity and cost factors militate against the use of this type of device in a retrofit application.

5.3 ULTRASONIC FUEL SYSTEM

The Ultrasonic Fuel System, developed by A. K. Thatcher of Merritt Island, Florida and E. McCarter of Orlando, Florida, is similar in function and operation to the Electrosonic Fuel Induction System described above. It is a computer-controlled fuel delivery system which incorporates a fuel pump, injectors, an air-fuel mixing chamber with an ultrasonic atomizer, and a fuel computer-controller. The basic function of the device is to control fuel flow so as to maintain a fixed, lean air-fuel ratio over a range of vehicle operating conditions.

Engine air intake flow and power output are controlled by a conventional butterfly valve (throttle) linked to the accelerator. Fuel flow-rates required to maintain a fixed air-fuel ratio are pre-programmed and computer-controlled on the basis of intake manifold pressure, engine speed, and ambient temperature sensor signals. Fuel is delivered to the mixing chamber/atomizer by a metering pump and two injector nozzles which direct the fuel toward the active surface of the ultrasonic unit. The vibrating surface acts to produce a stress in the fluid which breaks it up into microscopically small particles, thereby achieving fine atomization and an even dispersal of fuel in the air flow (Refs. 12, 13). Unlike the Electrosonic device, this system does not measure air flow-rates or provide fuel-flow control in a closed-loop sense.

The original embodiment of this invention was designed to maintain a fixed air-fuel ratio of 19 or 20 at all off-idle conditions. The system has since been modified to incorporate an additional computer circuit which provides for 30-percent enrichment of the mixture under acceleration conditions (Ref. 14).

The system has been installed and is presently operating in a 1972 Plymouth Duster, 225 CID 6-cylinder engine with the device set to produce a nominal air-fuel ratio of 19. The inventors report that the fuel economy of this vehicle has been improved by 25 to 30 percent, primarily as a result of the lean-mixture operating capability provided by the ultrasonic atomizing process. This figure is based on a 1500-mile on-the-road test of the Duster vehicle, mostly at high speeds near 70 miles per hour (Ref. 14). No other fuel economy tests of this system have been made.

Emission test results for this same vehicle were reported in Ref. 12 as follows.

Emission Test Results, g/mi

	HC	CO	NO_x
Without Device*	6.6	5.0	3.0 - 8.0
With Device	0.5	0.9	1.0 ± 30%

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*Standard carburetor

According to Ref. 14, these results represent average emissions over the hot start cycle of the 1975 CVS test; therefore, they do not reflect the emissions penalty associated with engine operation under cold start and warmup conditions. The inventors have no other formal test information to submit at this time.

Since this system appears to be based on the same operating principals as the Electrosonic device, the comments made earlier concerning the potentialities for fuel economy improvement with ultra-lean operation also apply to this device. The potential for emission control with this system cannot be assessed on the basis of the incomplete test evidence provided, which is limited to the hot start steady state portion of the CVS test duty cycle.

Disadvantages of high cost and complexity also apply to the Ultrasonic Fuel System. It may be noted that the Ultrasonic device neither relies on nor benefits from the measurement of air intake flow or on the operation of a closed-loop fuel-flow control circuit. The inventors consider the system suitable for retrofit application and foresee no complex installation problems.

This system is presently in an early stage of development. The inventors estimate the manufacturing cost at about $50.

5.4 CAL-TECH SUPER CARBURETOR

The Cal-Tech "Super Carburetor" reported in Ref. 15 was erroneously identified as a new development supported by funding from General Motors. In actuality, the device referred to in the article is a special research test unit application of the Electrosonic Fuel Induction System which is being used in the hydrogen enrichment fuels development programs at the Jet Propulsion Laboratory. The Electrosonic System is discussed in detail in Section 5.2.

5.5 AIR VALVE CARBURETORS (IN GENERAL)

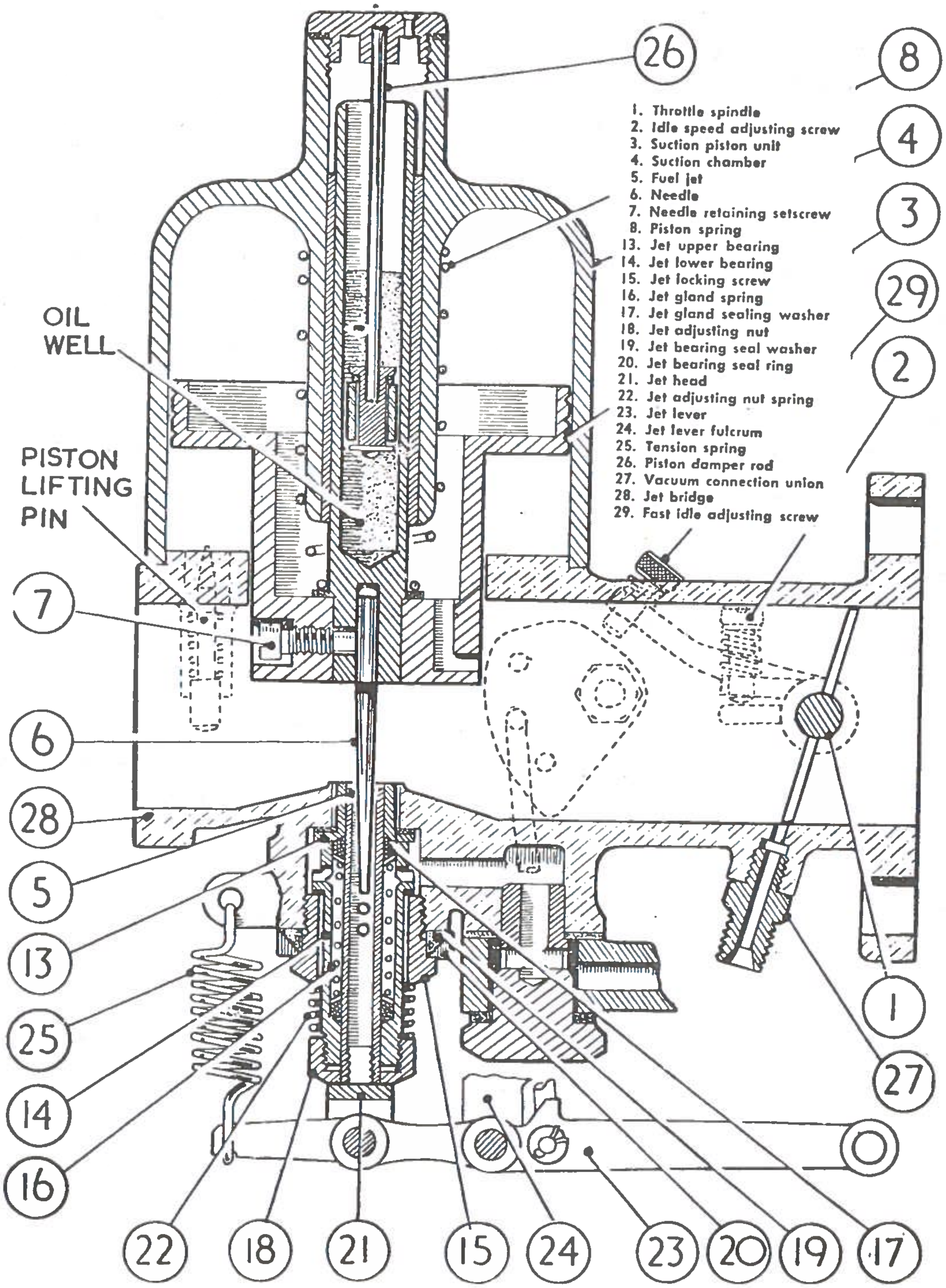
The air valve type carburetor, sometimes referred to as a constant depression carburetor, is used on a large number of British automobiles as well as some models of Japanese and Swedish automobiles. Because of its potential for providing good fuel atomization and the simplicity and variety of its mechanical arrangements, a number of such carburetors have recently appeared. Two such carburetors, the Kendig and the Woodworth, are discussed in following Sections 5. 6 and 5. 7.

The operation of this type carburetor involves a variable restriction which maintains a relatively constant pressure drop throughout the air flow range of the engine. By a mechanical arrangement, the position of the restriction device is used to meter the desired quantity of fuel.

The primary advantage in this type carburetor is derived from the variable restriction which could permit a high and relatively constant velocity to be maintained in the fuel metering section over the entire range of engine power setting, including idle conditions. The main disadvantage lies in the mechanical difficulty to accurately control fuel flow over this wide range.

Figure 5-2 shows a sectional view of an SU carburetor which has been used for many years on British automobiles. The key component in this design is the piston whose upper and larger diameter rides in a suction chamber while the lower and smaller diameter provides a variable restriction in the air intake passage. A tapered needle projecting from the bottom of the piston varies the effective area of a fuel metering orifice as a function of the piston height.

In operation, the pressure drop across the piston is sensed by a vent at the backside of its smaller diameter which communicates to the internal side of its larger diameter. This provides a lifting force on the piston since the external side of its larger diameter is vented to atmosphere. The piston rises and arrives at a position where the pressure difference over that area balances the piston weight. Piston height is therefore variable as a function of engine air flow.



1. Throttle spindle
2. Idle speed adjusting screw
3. Suction piston unit
4. Suction chamber
5. Fuel jet
6. Needle
7. Needle retaining setscrew
8. Piston spring
13. Jet upper bearing
14. Jet lower bearing
15. Jet locking screw
16. Jet gland spring
17. Jet gland sealing washer
18. Jet adjusting nut
19. Jet bearing seal washer
20. Jet bearing seal ring
21. Jet head
22. Jet adjusting nut spring
23. Jet lever
24. Jet lever fulcrum
25. Tension spring
26. Piston damper rod
27. Vacuum connection union
28. Jet bridge
29. Fast idle adjusting screw

Figure 5-2. The Basic SU Carburetor

Fuel enrichment during acceleration is provided by a dash pot in the piston shank which inhibits its upward travel and thus momentarily increases the pressure drop. This results in a higher suction pressure at the fuel metering orifice. Fuel enrichment during start is provided by a mechanical linkage which permits the fuel metering orifice to be lowered and thus increases its effective area.

5.6 WOODWORTH CARBURETOR

The Woodworth is a recent development of an air valve type carburetor, which under a license agreement is planned for manufacture by the C. P. Auto Products Company of Los Angeles, California. The carburetor will be marketed as a replacement for original equipment based on claims of reduced exhaust emissions and improved fuel economy (Ref. 17).

This carburetor incorporates a conventional air throttle butterfly and fuel float chamber. Its other major components are a diaphragm-actuated secondary butterfly valve which controls the primary fuel metering orifice, a diaphragm-actuated air bleed valve which provides a secondary fuel metering control and a spray bar which assists in the atomization of the fuel (see Fig. 5-3 and Ref. 16).

In this embodiment of the air valve concept the secondary butterfly valve provides a relatively constant pressure drop for the range of engine air flow requirement by its variable position which is controlled by a diaphragm actuator which senses pressure in the downstream metering section. The secondary butterfly shaft in turn is mechanically linked to a fuel metering orifice to provide a desired variation in effective flow area. This orifice communicates through a passage in the body to a plurality of holes in the spray bar. Within this passage is a variable air bleed which modifies the fuel flow to the spray bar. Control of this variable air bleed is provided by a second diaphragm actuator which senses manifold pressure.

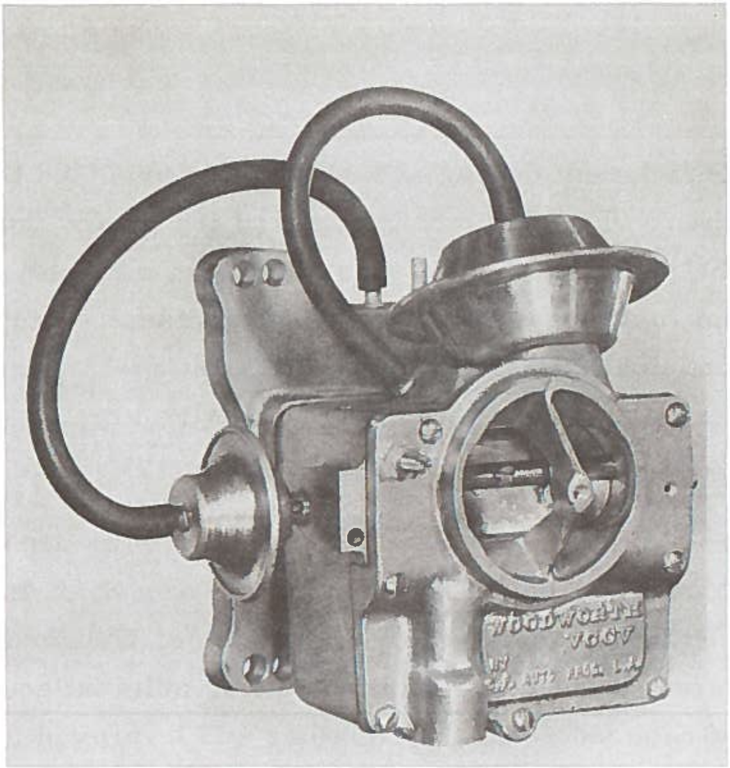


Figure 5-3. Woodworth Carburetor (Ref. 17)

The secondary butterfly valve and its actuator controls the position of the fuel metering orifice in a manner basically similar to the Kendig carburetor discussed below. In this carburetor the constant pressure in the intermediate chamber indirectly results from a variable restriction, due to feedback by the diaphragm actuator, while in the Kendig carburetor the pressure drop is a direct result of the variable restriction.

The variable air bleed and its manifold pressure-sensitive diaphragm actuator which modifies the fuel flow is the unique feature of this carburetor. Its operation is best illustrated by its functional response to the different engine operating modes. During engine start when the manifold pressure is high the air bleed is highly restricted which increases the fuel flow to enrichen the mixture. At cruise the reduced manifold pressure results in an air bleed which modifies the fuel flow to provide the best economy air-fuel ratio. During acceleration and at W. O. T. when manifold pressure is again high, enrichment is provided as in the engine start mode. During deceleration when manifold pressure is at the minimum, the air bleed is sufficiently high as to cut off the fuel flow.

Exhaust emission and fuel economy data obtained on a 1973 Chevrolet Impala during a test conducted by Automotive Environmental Systems, Inc. were (Ref. 18):

	Emissions, gm/mi				
	HC	CO	CO_2	NO_x	MPG
Hot Start	5.353	14.844	615.7	3.658	13.41
Steady State at 45 mph	1.894	2.762	418.0	3.393	20.72

This test was conducted in accordance with the CVS-72 federal test procedure except that the vehicle was operated from a hot rather than the specified cold start condition. Modifications have been made to the carburetor since these results but additional tests have not yet been performed. It is not possible to compare these fuel economy values with those of contemporary 1973 Chevrolet Impala vehicles because the cold start test was not performed; of course cruise fuel economy values are always higher than those obtained for simulated urban driving cycles.

The potential for a reduction in exhaust emissions and improvement in fuel economy for this carburetor is primarily in the refinement in fuel metering provided by its variable air bleed device. Some improvement in fuel vaporization, with attendant benefits, is possible but the low velocity in the mixing chamber reduces this potential.

From discussions with the inventor, Reference 17, it was understood that the carburetor normally operates at a 15:1 air-fuel ratio. At cruise conditions under light load, however, the action of the variable air bleed device raises the mixture ratio to approximately 17-18:1. For this particular condition, a small improvement in fuel economy (~2 percent) would be expected over operation at an air-fuel ratio of 16 (as in contemporary carburetors).

Some improvement in fuel economy would be expected from the quick release action of the "choke" and by the effective cutoff of fuel during deceleration. However, there are no data by which these benefits can be quantified.

An improvement in fuel atomization is inherent by the plurality of discharge orifices in the spray bar. The benefit of this configuration, however, is offset by the low velocity condition that exists in the intermediate chamber. Therefore, fuel atomization would not be expected to be significantly better than that provided in a conventional carburetor.

5.7 KENDIG CARBURETOR

The Kendig is an air valve carburetor currently under development by Pollution Control Industries of Torrance, California. Its primary claim is a reduction in exhaust emissions. Some claim is made for an improved fuel economy (Ref. 19).

The carburetor is of a simple construction as shown in Figure 5-4. The primary components are a dual throttle plate, a dual spring loaded "venturi" plate, a fuel spray bar, a fuel metering device and a conventional fuel float chamber.

The spring loaded dual "venturi" plate functions to maintain a relatively constant pressure drop in the intermediate chamber wherein the fuel spray bar is located. This dual plate which deflects as a function of the engine flow is mechanically linked through a gear arrangement to a fuel metering orifice. This orifice which is at the end of a pick-up arm

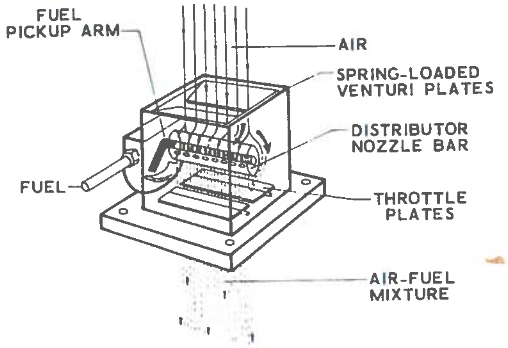


Figure 5-4. Kendig High Performance Carburetor

traverses an arc within a ramp of variable depth to change its effective flow area. This variable area orifice communicates through a passage to a plurality of holes in the spray bar. Enrichment of the mixture is provided during acceleration by an initial lag and subsequent temporary overshoot of the dual "venturi" plate. Limited choking action during start is inherent in the design since there will be some reduction in pressure in the intermediate chamber before the dual "venturi" plate opens. In the patent disclosure (Ref. 21), an override by metallic spring is shown which increases the force required to open the dual "venturi" plate. This would provide an additional choking action and such a refinement is currently being developed.

The results of tests performed by California Air Resources Board in February 1974 using a 1973 Pinto are shown in Table 5-1 (Ref. 20). It should be noted that these tests were run with a choke device which the manufacturer did not consider to be fully developed. It is his opinion that a malfunction of this device occurred during the test which compromised the performance of his carburetor. It is understood that the choke device has since been perfected. Exhaust emission and fuel economy data which reflects this improvement, however, are not available.

Any reduction in exhaust emission or improvement in fuel economy provided by this carburetor would probably relate to its capability to provide better atomization and uniformity of the fuel-air mixture delivered to the individual cylinders. In this regard it was noted that this design does not take full advantage of the potential associated with high velocity in the mixing section which is the primary advantage of an air valve carburetor. Velocity in the mixing section is relatively low, even at wide open throttle (WOT), because of the large cross-section in which the spray bar is located. The plurality of holes, however, would promote fuel atomization. The configuration of the dual throttle plate should also result in a better distribution of liquid fuel droplets than provided by a conventional single butterfly.

TABLE 5-1. CALIFORNIA AIR RESOURCES BOARD TESTS

	Emissions, gm/mi			Fuel Economy (mpg)
	HC	CO	NO_x	
Baseline Tests				
1	1.48	15.00	3.09	19.08
2	1.65	14.32	3.27	20.99
3	1.75	15.73	3.36	19.77
Average	1.63	15.02	3.24	19.95
Kendig Carburetor Tests				
4	1.34	6.43	1.40	16.43
5	2.05	50.06	1.99	16.21
6	2.27	8.48	1.51	15.98
Average	1.89	21.66	1.63	16.21

The manufacturer of this carburetor estimates that its cost to the consumer would be in the range of $65 to $70 for the device with an additional cost based on 1/2 hour labor for installation and 1/4 hour for adjustment and performance verification.

It is understood that this carburetor operates in the lean air-fuel ratio regime and is nominally set at approximately 16-18:1. On this basis, a small improvement in fuel economy (0 to 2 percent) would be expected over operation at an air-fuel ratio of 16(as in contemporary carburetors).

As in the Woodworth carburetor, the velocity in the mixing chamber is relatively low and, therefore, potential for improved fuel atomization from the spray bar is compromised. The dual throttle blade configuration, however, could promote better liquid droplet distribution in the manifold and thus permit the lean mixture ratio operation indicated above.

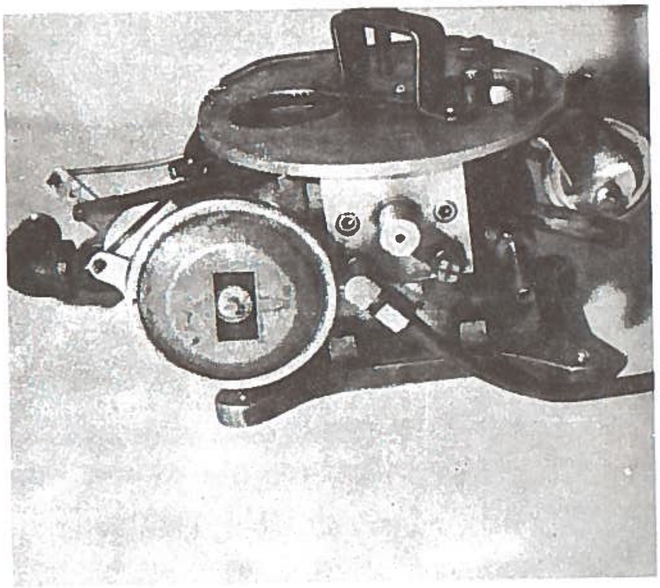
5.8 ARPAIA FUEL INJECTION CARBURETOR

The patented Arpaia Fuel Injection Carburetor (Figure 5-5) is a development of Bruin Engineering, Inc., Lincoln, Nebraska. It contains a single, adjustable fuel valve to control fuel flow over the full range of engine operating conditions (Refs. 22 and 23).

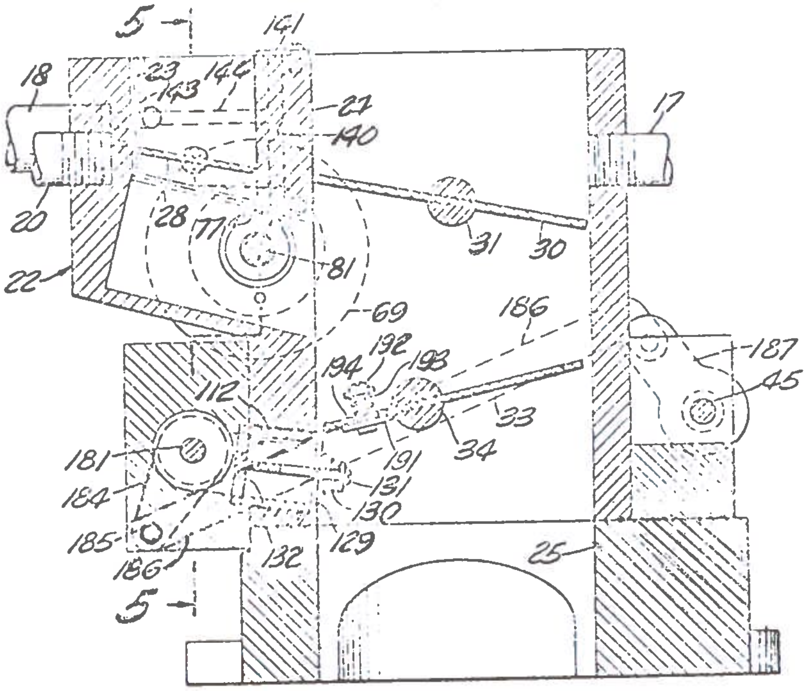
The main body of the carburetor contains both a primary and a secondary air passage which converge in a Y configuration to a discharge passage leading to the intake manifold. Air flow through both the primary and secondary air passages is modulated by separate butterfly valves connected to the accelerator pedal linkage. The linkage is configured such that the high velocity primary air passage is operative during the idle and medium speed modes of operation. Above 40 to 45 miles per hour and during wide open throttle acceleration, the secondary throttle valve comes into operation, permitting additional air flow.

The fuel control valve and supply port is located in the high velocity primary air passage. The fuel is discharged laterally across this passage to insure increased turbulence and mixing with the intake air. Fuel is maintained under a positive pressure with any excess being returned to the supply pump. An air flow butterfly-type sensing valve, located in the discharge passage of the carburetor, is utilized in conjunction with a manifold pressure sensing system and the automatic choke to regulate the fuel flow under the full range of operating conditions. Exhaust gases are utilized to provide heat to the automatic choke and are in turn injected into the intake manifold as a function of manifold pressure. Provision is also made to induct crankcase blowby gases into the primary air passage.

Typical air-fuel operating ranges for this device are claimed to be as follows: during cold start, the air-fuel ratio is 10-12:1 while under cold engine acceleration it is approximately 12:1. Hot engine acceleration is stated to be 14:1, while normal cruise is in the range of 14-15:1 and deceleration is at 16-18:1.



(a) Photograph (Ref. 22)



(b) Representation from patent (Ref. 22)

Figure 5-5. The Arpaia Fuel Injection Carburetor

Prototype units of the Arpaia Carburetor have been built and tested by the manufacturer on a 1972 Ford LTD (400 CID). Over a mixed driving route of approximately 320 miles comprising city (10 percent), mountain and desert highway (45 percent), and freeway driving (45 percent), the test vehicle was reported to attain 17.8 miles per gallon (+18.7 percent) compared to 15.0 miles per gallon for the same vehicle equipped with the original equipment carburetor. A 160-mile test in traffic driving in Southern California resulted in 13.8 miles per gallon (+32.7 percent) compared to 10.4 miles per gallon for the baseline vehicle.

Two, hot-start seven mode emissions tests were conducted by Olson Laboratories on the same 400 CID Ford used in the fuel economy runs, above. Results of these tests, with the Arpaia Carburetor, were as follows. Baseline tests were not conducted.

	gm/mi		
	HC	CO	NO_x
Test No. 1	2.31	38.11	2.11
Test No. 2	1.66	46.03	1.76

Bruin Engineering has made application to the California Air Resources Board (CARB) for certification of the Arpaia Carburetor as a replacement part. Testing has not yet been conducted by the CARB.

It was stated by Bruin Engineering that production rates of 1000 units per week could be achieved within 90-120 days of initial production startup.

The unit is offered as a replacement carburetor for operation on gasoline, gasoline with additives (e.g., alcohol), or gaseous fuels (LPG, etc.) and is claimed to provide improved fuel economy, increased power (7 to 12 percent), and reduced emissions. The unit would replace existing 2V and 4V carburetors. Adapter plates would be required to fit individual models. The fuel valve would be tailored to meet individual engine requirements. The suggested retail price of the Arpaia Carburetor was indicated to be $109.95.

In summary, insufficient data is available to completely evaluate the Arpaia carburetor. Although significant fuel economy gains were reported by the manufacturer, it must be pointed out that these were single vehicle tests and therefore subject to variations in the driving habits of the drivers, variations in the effectiveness of the device on different makes and models of cars, and the condition of the baseline vehicle (properly tuned, etc.). It is also not known whether or not any changes in timing or idle mixture ratio were made at the time of installation of the test device. Emissions data available on the Arpaia consisted of two seven mode, hot-start tests and hence cannot be used to evaluate the ability of this device to meet the 1973-74 emission standards as claimed since the use of the 1972 CVS driving cycle is known to result in higher emission levels. The cold start required in the 1972 CVS test procedure will also result in higher HC and CO levels than with a hot start.

In principle, the Arpaia carburetor would appear to offer the possibility of improved fuel economy in several areas of operation. The use of the smaller diameter primary air passage (in which the fuel valve is located) will provide high velocity intake air and improved atomization of the fuel. The introduction of hot exhaust gases into the discharge passage may also result in some vaporization of the fuel, again tending to improve fuel economy. The actual magnitude of these effects is expected to be slight, however, since the carburetor operates at a conventional air-fuel ratio of 14 - 15:1 rather than in the lean regime. An additional area of potential fuel economy improvement arises from the fact that the Arpaia carburetor operates at a 16 - 18:1 air-fuel ratio during deceleration. This could result in a 10 to 15 percent improvement during the deceleration mode of operation, although the total contribution to improved fuel economy would depend entirely on the particular driving conditions involved.

Based on the above considerations, it is recommended that further evaluation of the Arpaia carburetor be held in abeyance until more substantive data are made available by the manufacturer.

5.9 DRESSERATOR SYSTEM

The Dresserator System is a development of Environmental Technology, Santa Ana, California, a division of Dresser Industries, Inc., Dallas, Texas. The system as described in Ref. 24 comprises a commercial air filter with smoothed air flow path; an atomizing Dresserator core which, with a pressure fuel system, replaces the carburetor; a single plane intake manifold; and enlarged and insulated exhaust manifolds. Basically, the system is designed to permit engine operation at lean air-fuel mixtures, thereby providing emission control benefits and improved fuel economy.

The manufacturer states that the major portion of the emission benefits derived from this system comes from the improved combustion provided by the Dresserator carburetor. This device is a form of variable geometry venturi atomizer which is linked with a fuel metering apparatus, permitting control of air fuel ratio to some nominal level. The venturi is a mechanically activated variable area device designed to maintain the flow of air and fuel at the speed of sound through the throat over most of the operating range of the engine. Fuel is injected from a spray bar upstream of the venturi. Fuel flow rate and the venturi size are simultaneously controlled by linkage with the vehicle foot accelerator pedal.

Specific details concerning the configuration and operation of the components of the induction system are lacking. Figure 5-6 (Ref. 25) shows three successive design generations of the variable area venturi. Configuration III, the most advanced design, incorporates fixed jaws with a transverse sliding element which varies the flow area through the venturi. The manufacturer claims that the sonic feature of this design produces a very homogeneous air-fuel mixture which behaves like a colloidal suspension, producing minimum impactation on the walls of the intake manifold and providing more uniform cylinder-to-cylinder distribution. These factors contribute to the ability of the Dresserator system to operate at lean air-fuel ratios of from 18 to 19:1. The sonic feature is

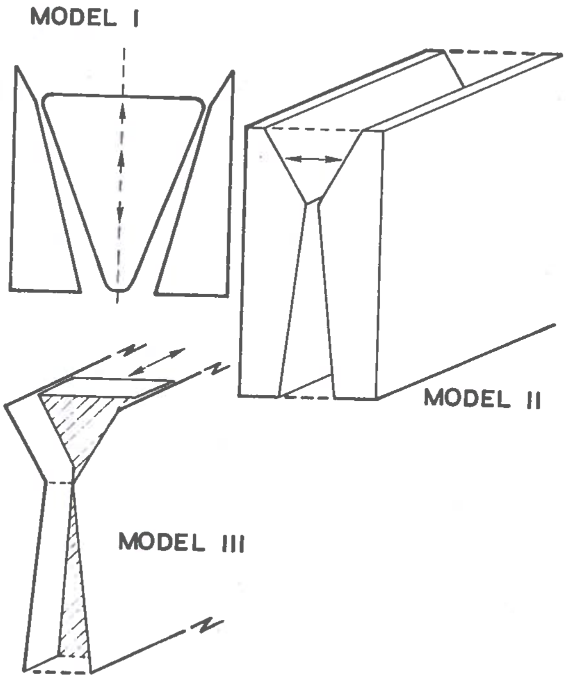


Figure 5-6. Dresserator Models (Ref. 28)

also asserted to permit very close control of air-fuel ratio as a result of the constant speed feature of the flow through an opening of known size acting as a mass flow indicator and control device (Ref. 24).

The manufacturer claims and confirming tests demonstrate that the device meets the 1975 California emission standards without the use of a catalytic converter. A number of Dresserator system emission tests have been made with results such as those shown in Table 5-2. All of these test data were reported by the manufacturer, except for entry No. 2 which shows the results of a confirming test conducted by the California Air Resources Board Laboratories (May 25, 1973). It is noted that the Dresserator testing has largely been conducted with disconnected vacuum advance. Although fuel economy has not been an object of study, the manufacturer claims a 5- to 10-percent improvement in fuel economy under these conditions and believes

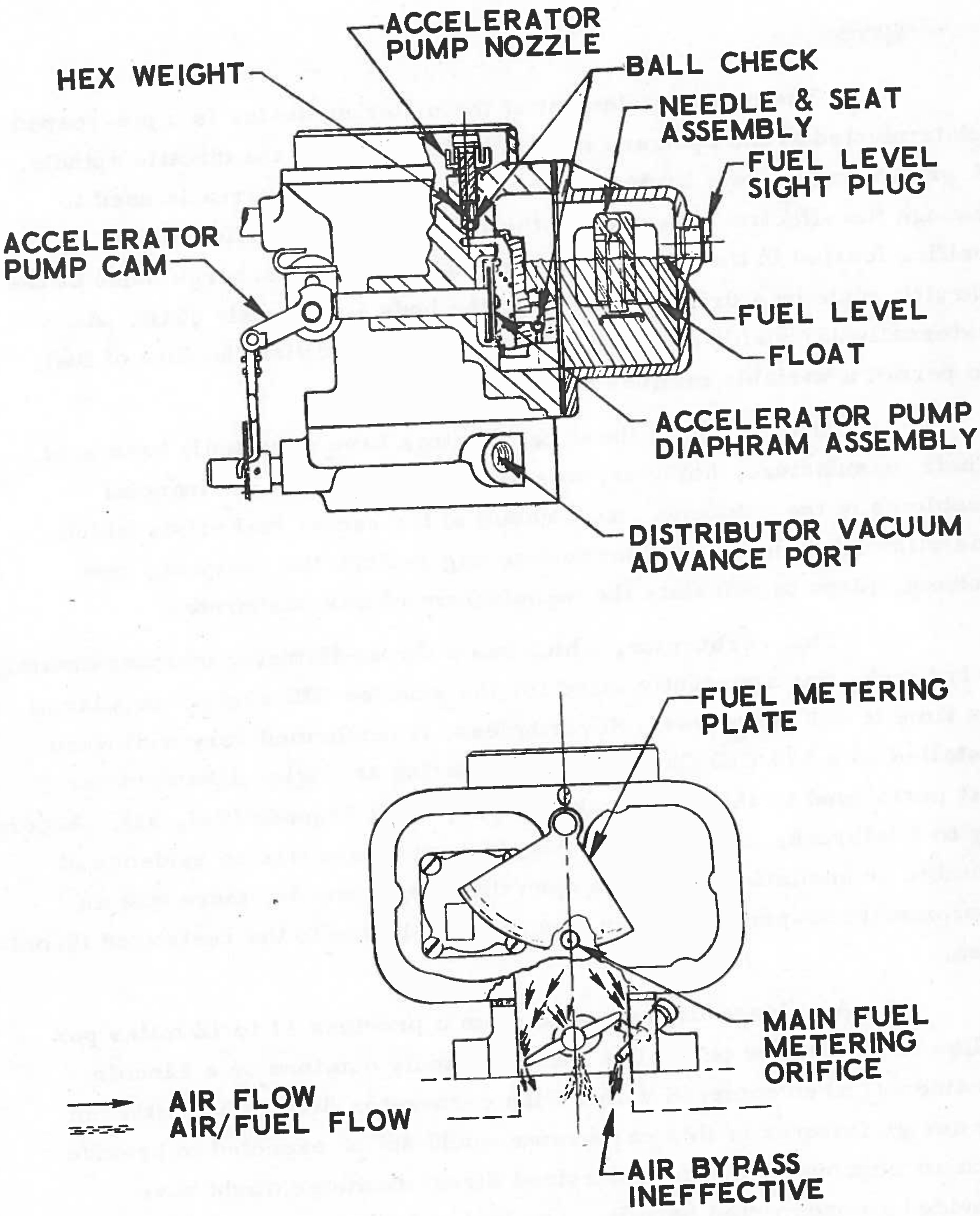


Figure 5-7. Fish Carburetor (Ref. 30)

The movable element of the metering device is a pie-shaped plate pivoted at the apex and mechanically linked to the throttle spindle. A groove in the plate having a variable cross-section area is used to change the effective flow area of the main metering orifice. This orifice located in the fuel float communicates with discharge holes at the throttle plate by a drilled passage in the body and throttle shaft. An externally adjustable air bleed in the passage modifies the flow of fuel to permit a variable mixture ratio.

Over 6,000 of these carburetors have reportedly been sold. Their manufacture, however, was stopped in 1965 due to financial problems of the company. As a result of the recent fuel crisis which has stimulated the market for fuel saving devices the company, now solvent, plans to reinstate the manufacture of this carburetor.

This carburetor, which has a throat diameter of approximately 1-1/2 inch, was apparently sized for the smaller CID engines popular at the time it was conceived. Nevertheless, it performed very well when installed on a 370 CID Chrysler engine during an engine dynamometer test performed by the Edelbrock Company in El Segundo (Ref. 32). According to Edelbrock, it had a crisp response and there was no evidence of stumble or hesitation. At wide open throttle, however, there was an approximate 30-percent power loss apparently due to the restricted throat area.

A mileage improvement from a previous 11 to 12 miles per gallon to 15.7 miles per gallon was reportedly obtained on a Lincoln Continental when equipped with a Fish carburetor (Ref. 31). Although the design features of this carburetor would not be expected to provide such an improvement, the undersized throat diameter might have provided an unexpected benefit. The high velocity created by the air demand of this large engine could improve fuel atomization to permit leaning of the fuel mixture. By this mechanism, some improvement in fuel economy might be attained. In this case the sonic velocity in the throat which probably prevailed would provide very good fuel atomization and attendant benefits.

The basic features of this carburetor would not be expected to provide an improvement in fuel economy. Because of its small throat diameter, however, its use on a large CID engine could provide an improvement in fuel economy. This improvement would be the result of improved fuel atomization which could permit it to be operated at lean air-fuel ratios. Such improvement, however, would probably not be large (e.g., ~4 percent improvement at air-fuel ratio = 19 to 20, compared to conventional operation at air-fuel ratio = 16).

5.11 GELB DIGITAL CONTROLLED CARBURETOR

The Gelb Digital Controlled Carburetor is a computer-controlled fuel induction system designed to deliver a preset air-fuel mixture to the engine over a range of vehicle operating conditions (Ref. 33).

The system incorporates four principal components: an air mass flow sensor, a fuel metering pump, a gas generator chamber containing an electrical resistance type flash heater to vaporize the fuel, and a fuel flow computer controller. Engine power is modulated by means of a conventional accelerator pedal linkage which operates an air control butterfly valve at the carburetor intake (Figure 5-8). The air mass flow is measured by an air impact valve located downstream of the butterfly valve. Fuel flow is computer-derived and controlled in relation to the measured air mass flow so as to maintain the desired air-fuel mixture. Metered fuel is delivered through a fuel nozzle ring onto the flash heater in the gas generator chamber where it is converted to a fuel vapor. The fuel vapor is inducted into the intake air downstream of the butterfly valve and air mass flow sensing valve.

The system provides for mixture enrichment under warmup, idle, and acceleration as sensed by various engine operating conditions.

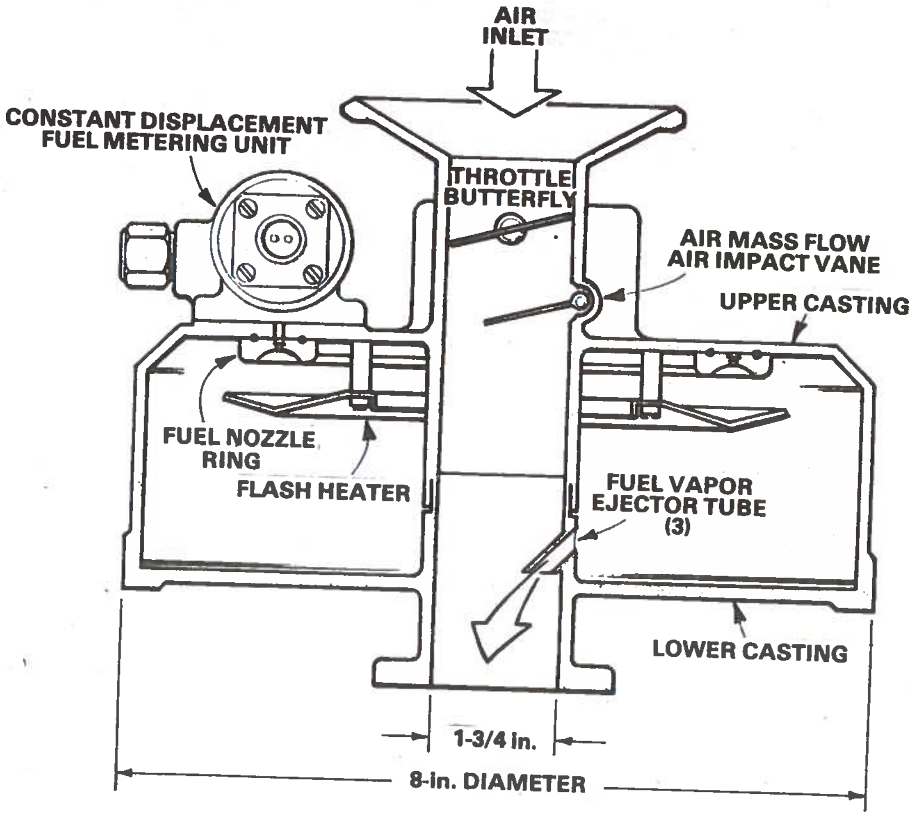


Figure 5-8. Gelb Carburetor (Ref. 33)

Enrichment under acceleration is accomplished by a closed loop system which compares engine revolutions per minute to throttle position and provides increased fuel as required by varying load conditions. A starting loop also provides increased fuel as a function of engine coolant temperature when the engine is being cranked at speeds below idle.

The function of the gas generator chamber is to provide a fuel vapor for induction into the engine. This, the manufacturer suggests, will provide a more closely controlled mixture of fuel and air, resulting in increased performance and fuel economy and lowered exhaust emissions over the 12.1:1 to 14.6 air-fuel ratio operating range.

Test data to support the manufacturer's claims of improved fuel economy and performance and reduced emissions are not available.

In theory, since the air-fuel ratio of the Gelb carburetor falls within the normal operating range of the conventional carburetor, no improvement in fuel economy attributable to the air-fuel ratio is anticipated. The vaporization of the fuel could result in a decrease in specific fuel consumption, as discussed in Section 3.4.1, if the specific conventional intake manifold design did not provide adequate vaporization over the range of vehicle driving conditions.

In view of the absence of any test data on the Gelb carburetor, it is recommended that further consideration of this device be withheld until such definitive data is supplied by the manufacturer.

5.12 POGUE CARBURETOR

A carburetor invented by Charles Nelson Pogue was reportedly sold in Canada during the 1930s on a money-back guarantee that it would deliver 100 miles per gallon gasoline. However, recent information indicates that Pogue's company never produced a carburetor (Ref. 34) and that Pogue feels the carburetor isn't applicable to the cars of today. Using patent drawings as a guide (Figure 5-9), such a carburetor was built in 1941 and installed on a 1936 six-cylinder Chevrolet. It was claimed that this installation provided mileage in excess of 150 miles per gallon. A top speed limitation between 28 to 38 miles per hour, however, was noted (Ref. 35).

The distinguishing feature of the Pogue carburetor (Refs. 36, 37, and 38) is its vaporization of fuel within the carburetor assembly prior to its introduction and mixing with combustion air. Fuel under pressure from a conventional engine operated diaphragm pump is discharged from nozzles located in a lower mixing chamber. Fuel level in the chamber is controlled by a float valve which unseats at the desired level, thus providing a return of excess fuel to the inlet side of the pump. Air bubbled through the fuel in combination with some vaporization and atomization of the fuel discharged from the nozzles provides an air-fuel emulsion above the liquid fuel level. This emulsion is delivered by a

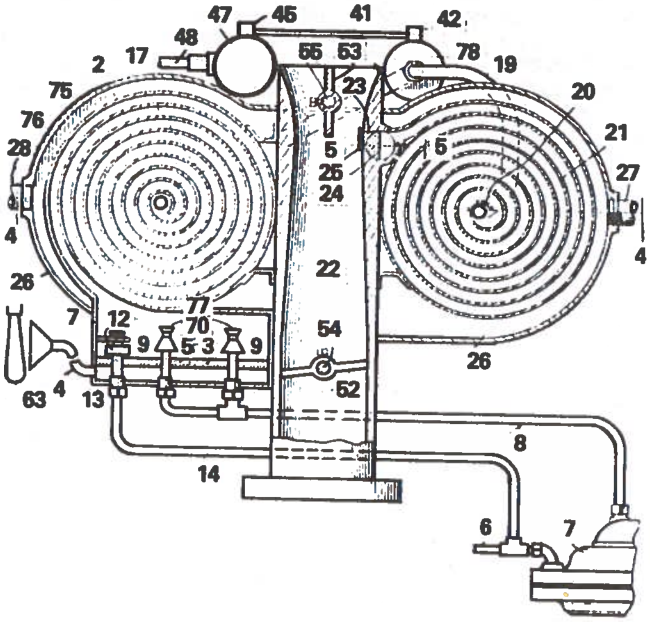


Figure 5-9. Representation of Pogue Carburetor (from patent) (Ref. 38)

vacuum operated pump to an upper chamber which contains a heat exchanger fed by gas extracted from the engine exhaust. The emulsion which is vaporized in this chamber is then metered with the combustion air.

The other elements of the basic carburetor are a manually operated choke of a conventional type and a butterfly throttle valve mechanically linked to a fuel vapor metering valve. The linkage between the throttle and metering valve is so arranged that a variable orifice within the metering valve is positioned to provide the desired fuel vapor/air mixture ratio for any given throttle position.

Although this design assures that fuel will be introduced in a vaporized condition, the quantity that would be produced by his arrangement would be extremely limited due to the high pressure drop through the heat exchanger. This probably explains the very low speed limitation noted in Reference 35.

The potential for improvement in fuel economy by the Pogue carburetor approach lies solely in its feature which provides complete vaporization of the fuel. As indicated in Section 3.4.1, the maximum benefit that might result from this condition is related to the degree of fuel vaporization provided by the specific intake manifold design of the vehicle being evaluated. For example, if the baseline intake manifold provided only 60 percent fuel vaporization during cruise conditions, complete vaporization might improve fuel consumption in the order of 16 percent. Claims of 100 to 150 miles per gallon fuel economy from this carburetor are technically unsupportable for the conventional passenger car. Claimed demonstrations of 100 miles per gallon in the past have involved special test vehicles with many modifications in equipment and operations, including:

a. Disconnecting cooling fan, water pump, and generator

b. Removing tread from tires

c. Inflating tires to very high pressures (~100 psi)

d. Use of oil instead of grease in bearings

e. Use of kerosene in the transmission

f. Driving at very low speeds (under 15 miles per hour)

g. Turning off ignition when going downhill

Obviously these modifications are not compatible with passenger car safety and durability requirements or with driver habits or needs.

5.13 FESSENDEN CARBURETOR SYSTEM

The Fessenden carburetor system combines two related patents, both by De Witt M. Fessenden of West Palm Beach, Florida. One relates to a fuel metering device which is positioned by a mechanical linkage to the throttle plate. The other relates to a blender and converter assembly which blends exhaust gas with the carbureted fuel-air mixture and vaporizes liquid fuel in the mixture. The claims for this system, which was installed by the inventor on a 1962 Buick, were that it gave better mileage, kept the engine cooler, increased the life of the muffler and, because the system burns dehydrated fuel, eliminated hydrocarbon and carbon monoxide emission (Ref. 39).

The main components of the fuel metering device (Figure 5-10) are a butterfly throttle valve, a main fuel metering valve controlled by a gear arrangement interconnected with the throttle linkage and an external idle fuel adjustment (Refs. 40, 41). The carburetor does not have a float chamber and fuel under pressure from a conventional engine driven fuel pump is delivered directly to the metering device. There are no special provisions for fuel enrichment during cold start or acceleration.

The blender converter assembly is incorporated in a housing mounted between the fuel metering device and the intake manifold. The carbureted fuel-air mixture from the fuel metering device together with gas extracted from the exhaust pipe are introduced into a small plenum at the top end of the housing. This mixture passes through a series of baffle plates prior to being delivered to the intake manifold. Figure 5-11 illustrates the system as installed in a car. No means are provided for metering of the extracted exhaust gas.

Data on a 1962 Buick from tests performed by AATCO, Inc., Auto Diagnostic Clinic, (Ref. 42) showed 100 parts per million (ppm) HC and 0.2 percent CO at 2500 revolution per minute (rpm); 500 parts per million (ppm) HC and 0.6 percent CO at idle (500 revolutions per minute (rpm). Accompanying the report was a notation that the average mileage was 22 miles per gallon at 75 miles per hour.

An improvement in the mixing and vaporization of fuel is inherent by the tortuous path of the mixture through the baffled section. This would provide a more uniform air-fuel ratio among the cylinders and thus permit an enleanment of the mean mixture ratio. On this basis, the system has potential for some improvement in fuel economy. A

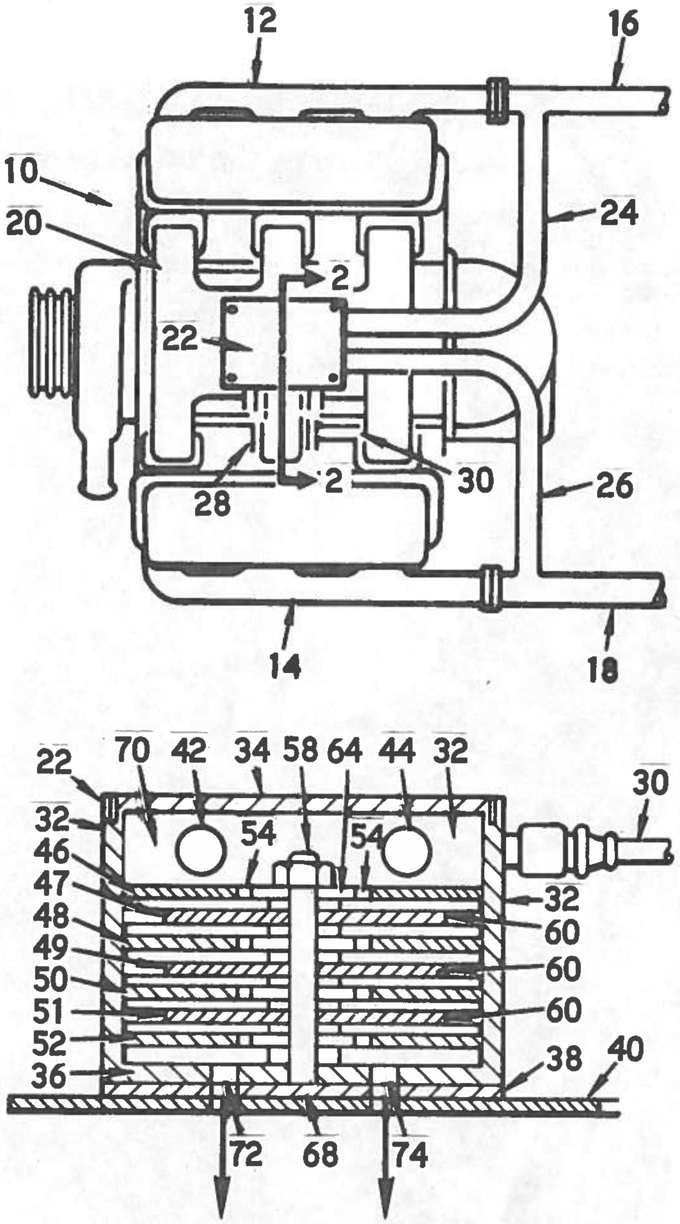


Figure 5-10. Representation of Fessenden Carburetor (from patent) (Ref. 40)

high pressure loss through the baffles, however, is also inherent in the design and could result in a significant loss in power at wide open throttle.

The fuel economy benefit potential by the fuel vaporization in the Fessenden carburetor is related to the degree of fuel vaporization

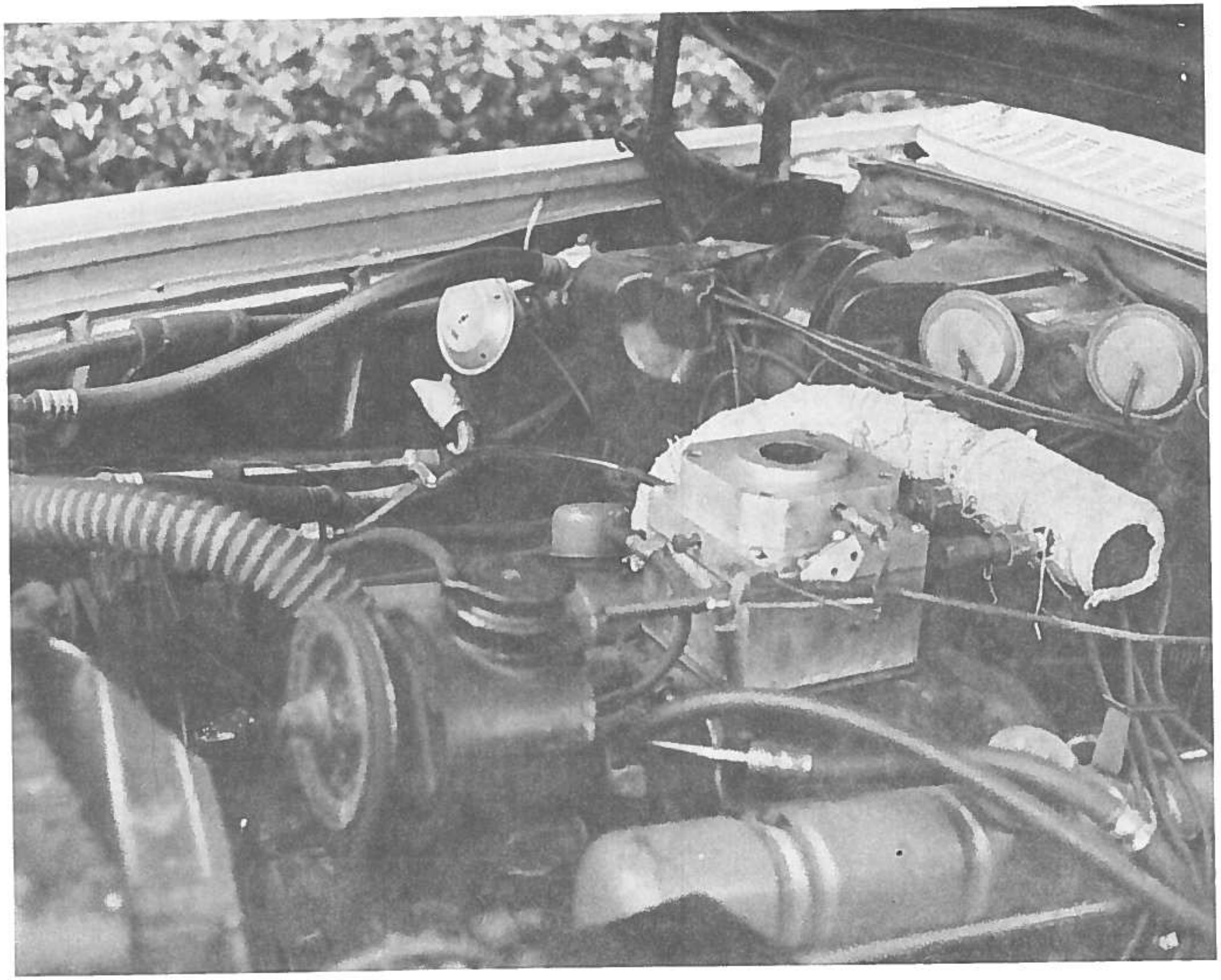


Figure 5-11. Fessenden Carburetor Installation

provided by the specific intake manifold design of the vehicle being evaluated or compared to. If the baseline intake manifold provides good vaporization under most driving conditions, then the benefits of the Fessenden approach would be slight. Conversely, an intake manifold providing poor vaporization would benefit to a greater extent, as indicated in Section 3.4.1.

5.14 VAPORATOR

The Vaporator is a product of Vapor Development Limited, Oxnard, California. This device embodies a scheme whereby a portion of the engine exhaust gas is utilized to heat and vaporize liquid gasoline so as to deliver the fuel to the engine in the form of a gas. The inventors assert that the device yields all of the combustion advantages of lean operation associated with the use of a gaseous fuel (such as propane) without the need for a pressurized fuel tank and without the problems of supply associated with the use of a secondary fuel (Refs. 43,44).

The system consists of three major components which replace the conventional carburetor: a vaporizer, a separator, and an air-throttling induction/mixing cylinder. Exhaust gas is extracted from the exhaust heat passage in the intake manifold and is fed through a one-way valve into a multi-orifice tube submerged in a reservoir of liquid fuel held in the vaporizer. The exhaust gas bubbles up through the fuel, atomizing it by agitation and vaporizing it by the transfer of heat from the exhaust gas. The mixture of exhaust gas and fuel is passed through a labyrinth separator to remove droplets of liquid fuel entrained in the mixture. The mixture then passes through a fuel flow control valve and is injected into the mixing cylinder below an air-throttle butterfly valve. The fuel valve is synchronized through a linkage with the air valve to control air-fuel ratio. A schematic of the apparatus drawn by the inventors is shown in Figure 5-12. The water injection feature shown in the drawing represents an early version of the device and has since been deleted from the system.

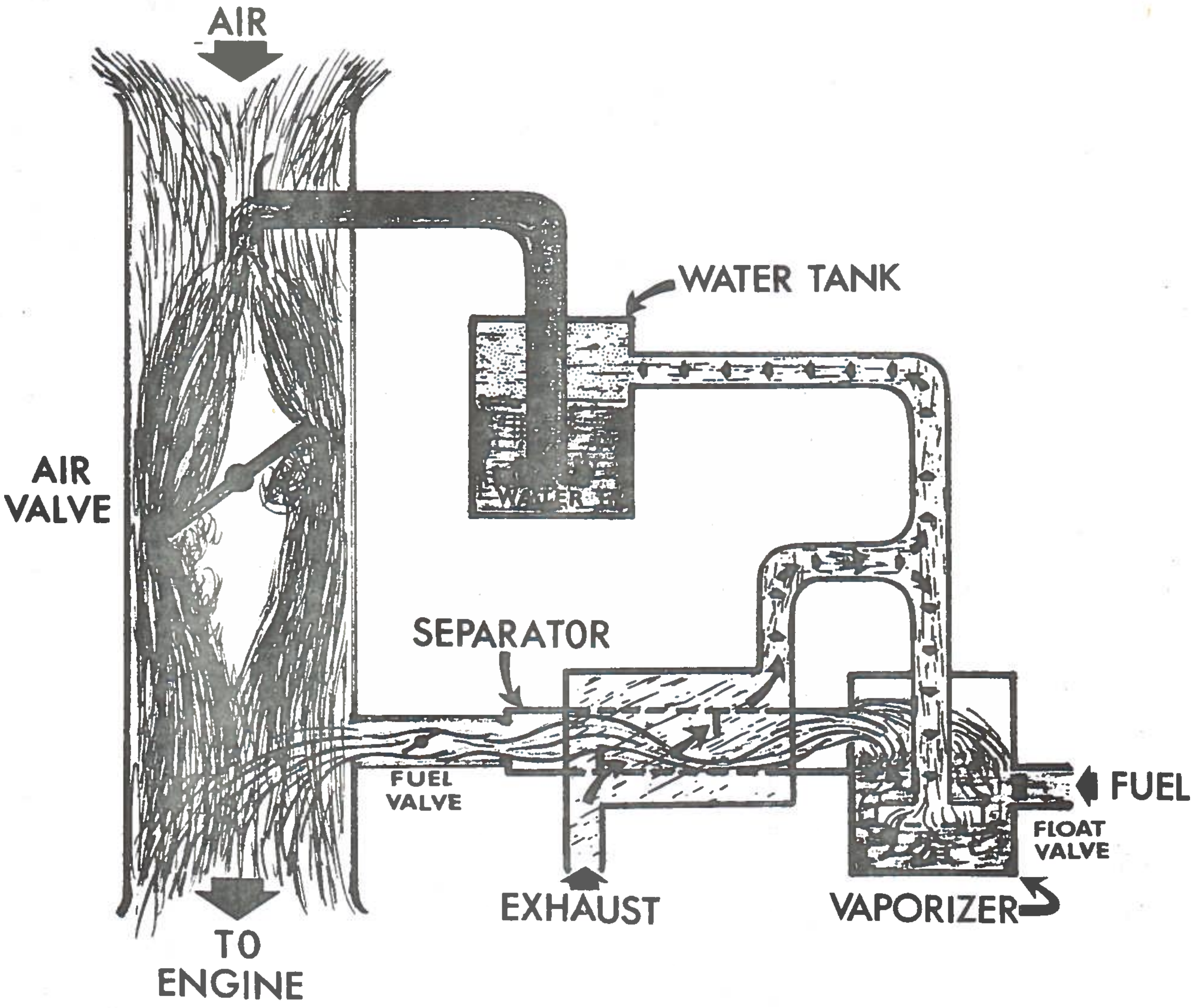


Figure 5-12. The Vaparator
(Ref. 44)

Approximately 5 to 18 percent of the exhaust gas is recirulated to provide sufficient heat for the vaporized quantities of fuel needed from idle to full-throttle engine power output. The recirculated gas also operates to control NO_x emissions in the manner of a conventional exhaust gas recirculation (EGR) emission control device. The system is designed to provide a lean operating capability at the level of about 17 to 1 air-fuel ratio. Mixture enrichment is provided during acceleration for better performance and driveability. On deceleration, fuel flow is cut off until the manifold pressure recovers to a preset level; thereby, the inventors expect to eliminate the characteristically high HC deceleration emissions observed with conventionally carbureted systems.

Three prototype models of the system have been built and various refinements have been made. One model has been installed in a 1965 Dodge Coronet, 361 CID V8 engine. This vehicle was road tested for fuel economy at 65 miles per hour cruise conditions using a calibrated miles-per-gallon meter. The inventors report 23 miles per gallon in this test compared with 14 miles per gallon before installation of the device. This result is qualified by the fact that the vehicle had 80, 000 odometer miles and that a new car of this make and model might get 17 miles per gallon at this speed.

The system has not been emission tested over a standard driving duty cycle. An idle test showed 150 parts per million HC and 0. 2 percent CO, which compares favorably to permissible levels for reregistering 1972 and 1973 model year cars in California. Baseline emissions for this vehicle were not obtained.

The inventors offer this development as a retrofit scheme for controlling emissions while simultaneously improving fuel economy for most automobiles. The selected air-fuel operating mixture of 17 appears to be close to optimum for minimizing HC and CO emissions at road load cruise conditions. With regard to NO_x control, the system incorporates exhaust gas recirculation, a well established technique for controlling the formation of this pollutant.

Induction of the charge as a gas tends to provide a more homogeneous mixture of air and fuel and a more uniform distribution of air-fuel ratio among the cylinders. This permits operation at a leaner mean mixture, thereby providing the emissions benefit described earlier. The system may also be expected to provide some fuel economy gain by virtue of several factors, including more complete combustion of the fuel charge, reduced pressure drop across the air throttle valve at the lean mixture position, and the proposed technique for cutting off the fuel supply during deceleration. Nevertheless, a well-tuned automobile operating over a representative driving cycle is not likely to exhibit the degree of improvement indicated by the road test results described above.

One disadvantage of completely vaporizing the fuel charge is that it results in higher mixture temperatures with lower volumetric efficiency and peak power output. It may also be mentioned that starting the Vaporator system under cold conditions requires a heating element to generate sufficient vapor for ignition and starting.

This device is in a very early stage of development. The inventors estimate that the manufacturing cost for the system would be about $30. The time required for installation of the device was estimated at 2 to 4 hours.

In summary, this device is being developed as an emission control retrofit system which additionally yields some benefits in fuel economy by virtue of the lean operating capability and improved combustion provided by vaporizing the fuel prior to induction. The maximum benefits available from vaporization are, as stated previously for the Pogue and Fessenden carburetors, totally dependent upon the vaporization characteristics of the intake manifold system to which the Vaporator is being added. At warmed-up, steady-state cruise conditions, such improved vaporization would not be expected to increase vehicle fuel economy more than a few (three to four) percent in most cases. This system may provide an additional increment of improvement by the proposed technique of shutting the supply of fuel during rapid acceleration manuevers, but the effect on fuel economy over a representative driving cycle may be negligible.

5.15 VAPIPE

Vapipe is an after-carburetor device which uses a heat pipe to vaporize fuel in the intake manifold. This device, which claims an improvement in fuel economy and a reduction in exhaust emissions, is under development by Shell International Petroleum Co., Ltd. (Ref. 45).

In the design, schematically shown in Figure 5-13, exhaust gas flows through an annular passage outside the heat pipe wall to vaporize a liquid within the heat pipe. This vapor expands and is thus transported to the intake manifold end of the pipe which incorporates a small tubular heat exchanger. The air-fuel mixture leaving the carburetor passes through this heat exchanger and condenses vapor in the heat pipe. The latent heat given up by this process is absorbed by the air-fuel mixture and in turn vaporizes liquid fuel in the carbureted mixture. Condensate formed is returned for revaporization at the exhaust end by the capillary action of a wick within the heat pipe.

The temperature of the vapor in the heat pipe is controlled to avoid high temperatures which could result in fuel-cracking and deposition. This is accomplished by engine coolant flow through an extension of the intake manifold heat exchanger. The upper end of this extension communicates with an inert gas reservoir. The pressure in the reservoir is adjusted for engine idle conditions such that the interface of the inert gas with the vapor in the heat pipe occurs at the lower end of the heat exchanger extension. At higher engine power settings, excess vapor formed in the heat pipe causes the interfaces with the inert gas to move upward in the heat exchanger extension. This excess vapor is condensed by the engine coolant which absorbs the latent

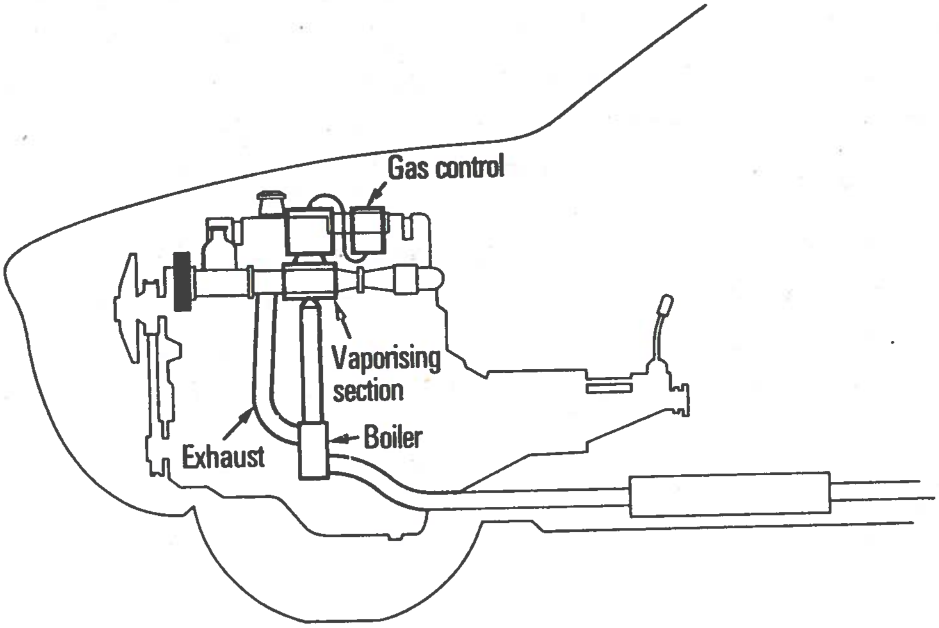


Figure 5-13a. Location of Vapipe

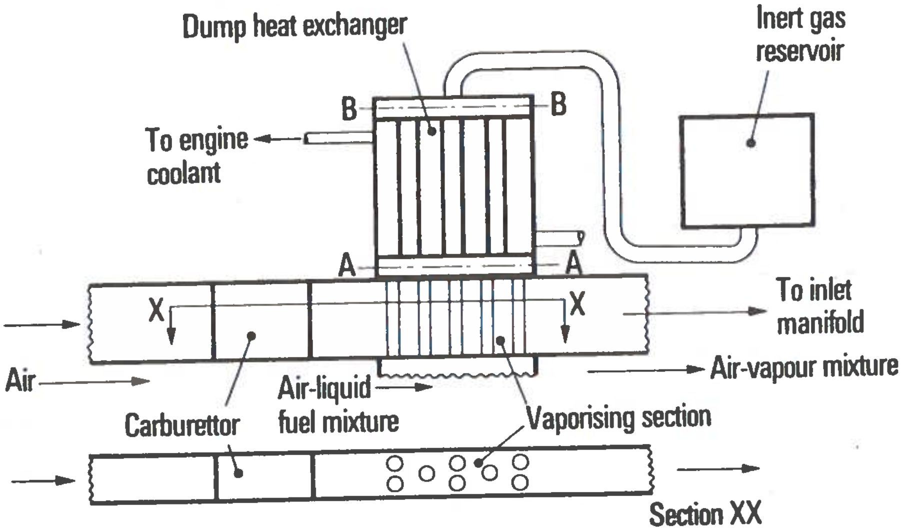


Figure 5-13b. Vaporizing Section and Gas Control System (Ref. 46)

heat. By this arrangement, relatively constant temperatures at the vaporizing section are maintained over the range of engine operating conditions.

Comparative exhaust emissions and fuel consumption data obtained during development tests are given in Table 5-3. Although the power loss resulting from the volumetric increase was not given it was noted to be higher than anticipated. Shell expects to reduce this loss with further development of the system.

A 30- to 40-percent fuel economy improvement (as shown in Table 5-3 for the U.S. Federal Tests) would not normally be expected by an improvement in fuel vaporization alone. In this case, however, an explanation might lie in the type of carburetor, presumably an S.U., employed during the test. The S.U. carburetor, being of a side draft type, is typically located on the intake manifold within a few inches from the cylinder intake valve port. Residence time of the mixture in the manifold is thus an absolute minimum. In addition, manifolds with this type carburetor do not incorporate a hot spot, typical in American installations. Therefore, the equilibrium air distribution condition of fuel at the intake port in the baseline configuration of Table 5-3 might be well below the limit indicated by the cutoff of the curve in Figure 3-6. Thus a significant fuel economy improvement could potentially exist for the Vapipe when used with a side draft carburetor as employed in numerous European vehicles. Conversely, this degree of improvement would not be expected if the Vapipe were to be incorporated on and compared to the baseline performance of U.S. passenger cars which employ intake manifold configurations with improved fuel vaporization characteristics.

In its present form, this design appears to be more of a laboratory device rather than one suited for production. To apply this device to an existing engine installation would require costly modifications to the intake manifold and the engine exhaust and coolant systems.

TABLE 5-3. EXHAUST EMISSIONS AND FUEL CONSUMPTION OVER VARIOUS TEST CYCLES WITH AND WITHOUT VAPIPE (Ref. 46)

Test Procedure	Legislative Limit			Standard Car Standard Setting			Vapipe Car Standard Setting			Vapipe Car Lean Setting		
	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
European ECE Type 15 test, gm/test	9.4	134	-	2.8	88.0	12.9	2.0	66.4	15.4	3.7	31.5	10.5
Fuel Consumption miles per Imperial Gallon (miles per U.S. Gallon)		-			14.6	(12.2)		18.0	(15.0)		17.4	(14.5)
Japanese 10 Mode Test, gm/km	3.8	26	3.0	1.7	22.8	2.6	1.2	19.8	2.9	1.2	2.1	3.1
Fuel Consumption miles per Imperial Gallon (miles per U.S. Gallon)		-			16.5	(13.8)		20.4	(17.0)		22.8	(19.0)
1973 U.S. Federal Test, gm/mile	3.4	39	3.0	2.3	18.3	5.6	1.6	21.1	3.8	1.7	5.9	4.5
Fuel Consumption miles per Imperial Gallon (miles per U.S. Gallon)		-			20.3	(16.9)		27.2	(22.7)		29.0	(24.2)
1975 U.S. Federal Test, gm/mile	1.5	15	3.1	2.2	16.4	5.4	1.5	18.8	3.7	1.5	3.7	4.6
Fuel Consumption miles per Imperial Gallon (miles per U.S. Gallon)		-			20.3	(16.9)		27.2	(22.7)		29.0	(24.2)

5.16 GRAYBILL "VMM" INJECTOR

The Graybill "VMM" injector is a carburetor device being developed by Mr. C. L. Graybill, Superior, Montana. The device is offered as a replacement carburetor for which improved fuel economy, increased power, and reduced emissions are claimed. According to the fact sheet presented by Mr. Graybill (Ref. 47), the device has no internal moving parts other than the conventional throttle plates and float valve assembly and can be adjusted to deliver any fuel mixture at any desired phase of engine operation. It is also claimed that the device does not restrict the air flow to the engine.

Mr. Graybill indicated that he is currently negotiating a contract for the further development of the carburetor and declined to discuss any details of the device, or the firm with which he is negotiating, other than to indicate that a 350 CID Chevrolet Malibu achieved 30 miles per gallon at 35 miles per hour cruise and 27 miles per gallon at 60 miles per hour. This compares quite favorably with the estimated fuel economy of 24 miles per gallon at 35 miles per hour and 20 miles per gallon at 60 miles per hour estimated for an intermediate size car.

It was reported in Reference 48 that the device was expected to sell for $20.00 to $25.00.

5.17 SUMMARY OF CARBURETOR DEVICES

Table 5-4 summarizes the more significant characteristics and developmental status of the carburetors described in detail in Sections 5.2 through 5.16. The fuel economy improvement claims noted in the table are those projected by the device manufacturer or promoter. Table 5-5 is a summary comparison of the major characteristics as they might relate to fuel economy improvement potential. Each such characteristic is addressed separately.

As noted in Section 3.4.4, the air-fuel ratio is one important characteristic impacting fuel economy. However, increases in air-fuel ratio to 20 would not be expected to increase steady-state cruise fuel economy more

TABLE 5-4. CARBURETOR DEVICES SUMMARY

Device	Type	System Components	Fuel Economy or Improvement Claimed	Emission Control Claimed	Performance Effects Claimed	Development Status/ Availability	Cost Factors (d)	
							Initial Hardware Cost to Owner	Installation Time (Hrs)
Electrosonic Fuel Induction System	Computer-controlled acoustic atomizer	Atomizer, computer, air flow transducer, fuel metering pump	20-25% (a)	1975 Fed. Standards (a, b)	No degradation (a)	Research prototype (120 units)	$50 (e)	--
Ultrasonic Fuel System	Computer-controlled acoustic atomizer	Atomizer, computer, fuel metering pump	25-30% (a)	1975 Fed. Standards (a)	Not Specified	Research prototype	--	--
Kendig Carburetor	Air-valve carburetor	Carburetor only	10-15% (a, b)	1975 Fed. Standards (a, b)	Not Specified	Develop-ment prototype	$65-70	.75
Woodworth Carburetor	Air-valve carburetor	Carburetor only	Improve-ment (a)	Improve-ment (a)	Not Specified	Research prototype	$100	1
Arpaia Fuel Injection Carburetor	Air-valve Carburetor	Carburetor only	15-30% (a)	1974 Cal. Standards (a)	7-12% HP Improve-ment (a)	Develop-ment prototype	$110	1
Dresserator System	Sonic variable - Venturi system	Atomizer, modified intake & exhaust manifolds	5-10% (c)	1975 Cal. Standards (c)	Not Specified	Develop-ment prototype	--	--

see next sheet for footnotes

TABLE 5-4. CARBURETOR DEVICES SUMMARY (Concluded)

Device	Type	System Components	Fuel Economy or Improvement Claimed	Emission Control Claimed	Performance Effects Claimed	Development Status/ Availability	Cost Factors (d)	
							Initial Hardware Cost to Owner	Installation Time (Hrs)
Fish Carburetor	Throttle-linked fuel metering carburetor	Carburetor only	30% (a)	None	Improvement (a)	In production prior to 1965	$85-90	--
Gelb Digital-Controlled Carburetor	Computer-controlled vaporizer	Vaporizer, computer, air flow sensor, fuel metering pump	Improvement (a)	Improvement (a)	Improvement (a)	--	--	--
Pogue Carburetor	Vaporizer	Carburetor only	150 mpg (a)	Not Specified	Not Specified	Experimental unit only	--	--
Vaporator	Vaporizer	Vaporizer/ separator/mixer	Improvement (a)	Improvement (a)	Not Specified	Research prototype	--	2
Fessenden Carburetor System	Vaporizer system	Carburetor, blender	Improvement (a)	Reduced HC, CO (a)	Not Specified	Experimental units only	--	--
Vapipe	After-carburetor vaporizer	Heat pipe, heat exchanger	30-40% (a)	Improvement (a)	Not Specified	Feasibility hardware only	--	--
Graybill VMM Injector	--	--	Improvement (a)	Improvement (a)	Improvement (a)	Research prototype	$20-25	--

NOTATION:
(a) Substantiating independent test data lacking
(b) Available data from independent tests does not support claim
(c) Available data from independent tests support claim
(d) Estimated by concept promoter
(e) Increase over conventional carburetor system

TABLE 5-5. COMPARISON OF CHARACTERISTICS (As related to fuel economy improvement potential)

Characteristic / Carburetor	Air-Fuel Ratio and Effects[1]	Mixing and Distribution Effects			Warmup Effects[5]	Choking Effects[6]	Deceleration Effects[7]	Hardware Availability for Testing[8]
		Atomization[2]	Vaporization[3]	Superheat[4]				
Electrosonic Fuel Induction System	A/F=17 to 23. Should enable small fuel economy improvement (1 to 5%) compared to A/F of 16.	Should improve fuel atomization in part throttle and low airflow regime.	N. A.	N. A.	N. A.	N. A.	N. A.	Should be available
Ultrasonic Fuel System	A/F=19 to 20. Should enable small fuel economy improvement (~4%) compared to A/F of 16.		N. A.	N. A.	N. A.	N. A.	N. A.	Unknown. One test unit presently on a car.
Kendig Carburetor	A/F=16 to 18. Should enable small fuel economy improvement (0 to 2%) compared to A/F of 16.	Fuel spray bar should give better mixing. Improved distribution due to lack of conventional throttle plate.	N. A.	N. A.	N. A.	N. A.	N. A.	Should be available.
Woodworth Carburetor	A/F~15 normally. A/F~17-18 at cruise under light load (due to variable air bleed device).	Fuel spray bar should give better mixing.	N. A.	N. A.	N. A.	Very fast acting choke	Fuel essentially cut off during deceleration when throttle is fully closed.	Should be available.

See page 5-49 for footnotes

TABLE 5-5. COMPARISON OF CHARACTERISTICS (As related to fuel economy improvement potential) (Continued)

Characteristic / Carburetor	Air-Fuel Ratio and Effects [1]	Mixing and Distribution Effects			Warmup Effects [5]	Choking Effects [6]	Deceleration Effects [7]	Hardware Availability for Testing [8]
		Atomization [2]	Vaporization [3]	Superheat [4]				
Arpaia Fuel Injection Carburetor	A/F=14-15 at cruise. Should have slightly poorer fuel economy compared to A/F=16.	Should improve fuel atomization due to high air velocity in primary flow passage.	Hot EGR flow may promote improved vaporization.	N. A.	May be some improvement in warmup due to hot EGR flow.	N. A.	F/A increased to 16-18 during deceleration. Should improve decel fuel economy.	Is available
Dresserator System	A/F=18-19. Should enable small fuel economy improvement (3 to 4%) compared to A/F of 16.	Sonic velocity in variable venturi should improve fuel atomization & distribution.	N. A.	N. A.	N. A.	N. A.	N. A.	Available to Ford; Availability to others not known.
Fish Carburetor	Normally operates at conventional A/F ratios (15-16). Has a controllable external air bleed to lean the mixture "as desired".	Possible improvement in distribution & atomization if small throat Fish carburetor is used with large CID engine.	N. A.	N. A.	N. A.	N. A.	N. A.	Should be available
Gelb Digital-Controlled Carburetor	A/F=14.6. Should have slightly poorer fuel economy than A/F=16.	N. A.	Total fuel vaporization should improve mixing and distribution.	N. A.	Vaporized fuel may promote faster warmup.	N. A.	N. A.	Availability unknown

See page 5-49 for footnotes

TABLE 5-5. COMPARISON OF CHARACTERISTICS (As related to fuel economy improvement potential) (Continued)

Characteristic / Carburetor	Air-Fuel Ratio and Effects [1]	Mixing and Distribution Effects			Warmup Effects [5]	Choking Effects [6]	Deceleration Effects [7]	Hardware Availability for Testing [8]
		Atomization [2]	Vaporization [3]	Superheat [4]				
Pogue Carburetor	Operating A/F unknown. Should be able to operate lean.	N. A.	Concept involves fuel vaporization to improve mixing and distribution.	N. A.	Hot exhaust gas in heat exchanger may promote faster warmup	N. A.	N. A.	Not available
Vaporator	A/F=17. Very small fuel economy improvement (~ 1%) over A/F=16; should be able to operate leaner.	N. A.	Concept involves fuel vaporization to improve mixing and distribution	N. A.	The 5 to 18% Hot EGR flow rate may promote faster warmup.	No choke used. Requires heating element for cold start.	Fuel flow cutoff on deceleration	Experimental units should be available
Fessenden Carburetor System	Operating A/F unknown. Should have potential to operate lean.	N. A.	Concept involves fuel vaporization to improve mixing and distribution.	N. A.	EGR flow may improve warmup.	No choke used. May have starting problems in cold weather.	N. A.	Two experimental units made
Vapipe	A/F=19-20. Should enable small fuel economy improvement (~ 4%) compared to A/F of 16.	N. A.	Concept involves fuel vaporization to improve mixing and distribution.	Could have some degree of superheat.	Vaporized fuel may promote faster warmup.	N. A.	N. A.	Experimental units only to date

See page 5-49 for footnotes

TABLE 5-5. COMPARISON OF CHARACTERISTICS (As related to fuel economy improvement potential) (Concluded)

Characteristic / Carburetor	Air-Fuel Ratio and Effects[1]	Mixing and Distribution Effects			Warmup Effects[5]	Choking Effects[6]	Deceleration Effects[7]	Hardware Availability for Testing[8]
		Atomization[2]	Vaporization[3]	Superheat[4]				
Graybill VMM Injector	Not disclosed		Not disclosed				Not Disclosed	

NOTES:

[1] Refers to the basic effect of air-fuel ratio on fuel economy at the warmed-up, steady-state cruise condition. Discussed in Section 3. 4. 4 and illustrated in Figure 14.

[2] Refers to the basic effect of the carburetor concept on atomization of the fuel in the carburetor, per se, and its subsequent effect on fuel and air distribution.

[3] Refers to the basic effect of the carburetor concept on vaporization of the fuel in the carburetor, per se, or on its subsequent effects in the intake manifold in terms of vaporization and distribution. Discussed in Section 3. 4. 1 and illustrated in Figure 6.

[4] Refers to the potentiality of the concept to fully vaporize the fuel and increase its temperature above the equilibrium air distillation temperature (see Figure 6).

[5] Refers to the capability of the concept to add heat during the engine warmup mode or to improve fuel vaporization during engine warmup.

[6] Refers to the choking characteristics of the carburetor concept.

[7] Refers to the capability of the carburetor to reduce fuel consumption during vehicle deceleration modes.

[8] Refers to the relative availability of a physical carburetor device for possible test evaluation.

than approximately four to five percent over that obtainable with conventional carburetors operating at an air-fuel ratio of 16.

Another important characteristic is the degree of fuel and air mixing and distribution from cylinder to cylinder, as noted in Sections 3.4.1 and 3.4.2. Conventional carburetor and intake manifold designs can provide adequate mixing and distribution under warmed-up, steady state cruise and WOT conditions as shown in Figures 3-11 and 3-12. However, during conditions of warm-up, idle, and light-load cruising conditions, fuel vaporization concepts (e.g., Arpaia, Gelb, Pogue, Vaporator, Fessenden, Vapipe) and fuel atomization concepts (e.g., Electrosonic, Ultrasonic, Kendig, Arpaia, Dresserator) could have more beneficial effects.

Similarly, those concepts which tend to promote faster warm-up (Arpaia, Gelb, Pogue, Vaporator, Fessenden, Vapipe) may reduce choking requirements with an attendant benefit in reduced fuel consumption during warmup. Also, concepts which reduce or shut off fuel flow during deceleration have the potential to reduce fuel consumption in this driving mode. However the total effects of such mixing and distribution and other improvements cannot be adequately quantified unless hot and cold representative test driving conditions (e.g., Federal constant volume sampling (CVS) hot and cold test driving procedures) are implemented which result in an integration of the total possible effects of the carburetor and induction system. As shown in Sections 5.2 through 5.16, such comparative test data is not available. Therefore, it is not possible at this time to accurately evaluate the fuel economy improvement potential of any given device. It can be broadly stated that, in the absence of emission control system requirements and constraints, it is unlikely that any of the proposed concepts would improve the fuel economy of a conventional U.S. passenger car (in the proper state of tune and at a cruise air-fuel ratio of 16) more than ~10 percent.

When emission control requirements are considered, however, the interactions of air-fuel ratio, spark advance (or retard), and exhaust gas recirculation (EGR) flow rates on HC, CO, and NO_x emissions are far too complex to permit simplistic estimates of combined effects on emissions and fuel economy. Thus, except for those carburetor concepts which permit lean operation (air-fuel = 18 to 20 or above), it would be expected that any new carburetor (such as those reviewed herein) would be subject to the same air-fuel ratio and spark timing constraints as conventional carburetors; thus there would remain only the potential for minor improvements in fuel economy due to improved mixing and distribution or improved warmup effects.

When lean operation is involved, its potential for concurrent reduction of HC, CO, and NO_x emission species at air-fuel ratios in the 18 to 20 range raises the possibility of realizing not only the potential fuel economy improvements of lean burning (four to five percent) and improved mixing and distribution (a few percent) but also of regaining fuel economy losses which have been caused by retarding the spark advance to reduce HC and NO_x emissions and by the utilization of EGR to further reduce NO_x. For example, when the Dresserator System with vacuum spark advance was installed on a 1973 Chevrolet (see Table 5-2, line 7), a 12-percent improvement in fuel economy was obtained with slightly lower NO_x levels than the baseline 1973 Chevrolet with EGR and no vacuum advance (see Table 5-2, line 6). HC and CO emissions were also reduced below baseline values.

In all cases, however, comparative tests on the appropriate Federal test cycle are required to fully evaluate the combined effects of any new carburetor concept on emissions and fuel economy; these data are not available today.

6. CLOSING REMARKS

There are, undoubtedly, many other specific approaches to carburetor improvement being conceived, developed, and promoted in the United States today, aside from those discussed above in Section 5. However, in all likelihood, they are addressed to the same basic problem areas: improved fuel atomization and vaporization, increased precision in fuel and air metering and air-fuel ratio control, and methods for extending the lean-misfire limits. These carburetor-improvement activities are not limited to the auto industry, per se, but extend across a wide spectrum of private endeavor, from individual inventors and entrepreneurs to industrial companies.

The inherent limitations of conventional carburetors with respect to maximization of automotive fuel economy potential have been well known for a long period of time. However, the conventional carburetor appears to have provided adequate means for obtaining a reasonable balance of power, driveability, and fuel economy until the incorporation of emission control techniques (retarded spark, exhaust gas recirculation, etc.) which required mixture enrichment to retain adequate driveability or which precluded achievement of minimum specific fuel consumption at a given engine speed and power level.

Specific carburetor improvements (e.g., improved precision and stability of air-fuel ratio control, altitude compensation, quick-release chokes, intake manifold heating) are in the process of implementation by the auto industry for the purpose of exhaust emission control; these same improvements should be also beneficial to fuel economy. Carburetor concepts which enable very lean operation (air-fuel ratio >20) for control of oxides of nitrogen are known to be in the development and evaluation stage; these approaches may also improve fuel economy, at least over alternative approaches to obtaining the same emission levels.

It should be borne in mind that although the carburetor is, of course, a key component with regard to fuel economy for a given engine, there are many other factors which have a strong impact on national automotive fuel consumption for the total automotive fleet. Principal factors include vehicle weight, vehicle-power-to-weight ratio, and individual driving habits, among others. Recent summarizations of these effects have been prepared by the Environmental Protection Agency (Ref. 49) and the Motor Vehicle Manufacturers Association (Ref. 50); it is recommended that these reports be examined by those interested in automotive fuel consumption reduction.

With regard to those specific carburetor devices delineated herein, it is important to realize that the data base available for evaluation of them in terms of fuel economy improvement potential is extremely limited and inadequate in both the comparative and statistical sense. In most cases, only one or at most a few cars are claimed to have been tested. There is a lack of definition of what the baseline test vehicle's condition (including state of tune) was prior to incorporating the new concept device. Standardized driving cycles are required in order to be able to make accurate comparative fuel economy evaluations. To date, in the absence of adequate fleet statistics for other road routes, the Federal Emissions Test Driving Cycle is the only such driving cycle so defined. Where such tests were claimed, they were not made with the cold-start portion of the test, thus precluding comparison with published Environmental Protection Agency fuel economy values for various model year vehicles. Also, very importantly, simultaneous emissions and fuel economy data are not available; these are necessary to determine compliance of the device with exhaust emission standards. Thus, comparison of these devices on the basis of currently available data is not possible.

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APPENDIX

REPORT OF INVENTIONS

A diligent review of the work performed under this contract has revealed no new innovation, discovery, improvement or invention.