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Highway Vehicle Retrofit Evaluation
Phase I
Analysis and Preliminary Evaluation Results

Volume I: Sections 1 through 3

M. G. HINTON et al.

November 1975

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16. Abstract

This report in two volumes presents an analysis and preliminary evaluation of selected used-car and light-truck fuel economy retrofit devices.

In particular, information is provided that depicts the performance characteristics of retrofit devices that have been brought to the attention of the Department of Transportation as having the potential to improve automotive fuel economy. The spectrum of devices includes carburetors, acoustic and mechanical atomizers, lean-bleed devices, vapor injectors, fuel modifications, inlet manifolds, drivetrain components, drag reduction techniques, driver aids, cooling fans, valve timing, tuneups, exhaust-related systems, engine oils, oil additives, and filters.

Included where possible, are analyses of the general operational principles of a given device and its possible effects on spark ignition engine operation in order to substantiate or explain the available test data.

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PREFACE

This report, prepared by The Aerospace Corporation for the U.S. Department of Transportation (DOT), Transportation Systems Center (TSC), as part of their Automotive Energy Efficiency Project, presents an analysis and preliminary evaluation of the potential of selected used car and light truck retrofit devices for reducing fuel consumption. A number of the more promising devices are recommended for experimental evaluation in a Phase II test program.

Over 20 representative classes of retrofit devices/concepts/techniques, including more than 130 specific items, were examined in the course of the study. A major portion of the analysis effort was directed to the evaluation of 16 advanced, novel, or new carburetors which had been brought to the attention of the Department of Transportation as having the potential to improve automotive fuel economy. The results of the carburetor analysis presented herein were also published in a separate interim report.(1)

In addition to carburetors, the spectrum of devices examined included: acoustic and mechanical atomizers; lean-bleed devices; vapor injectors; fuel modifications (additives, blends of water, alcohol, and gasoline); inlet manifolds; ignition systems; drivetrain components (radial tires, transmissions, overdrives); drag reduction techniques; driver aids; cooling fans; valve timing modifications; tuneups; compression ratio increases; exhaust-related systems (tuned exhaust systems, turbochargers, etc.); and engine oils, oil additives, and filters.

The preliminary evaluation results presented herein are necessarily based on and restricted to the results of the best comparative test data available for a given device or class of devices. In general, such comparative test data (before and after installation of a device in a vehicle), when available, are based on at most a few vehicles. Thus, it is not possible to extrapolate

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(1) A Review of Proposed Automotive Carburetor Concepts for Improved Fuel Economy, The Aerospace Corporation, Report No. DOT-TSC-OST-74-41, March 1975.

such test data to the general vehicle population. Therefore, wherever possible, an analysis was made of the general operational principles of a given device and its possible effects on spark ignition engine operation in order to substantiate or explain test data results.

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

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SECTION 1

SUMMARY

An analysis and preliminary evaluation were made of the potential of selected used car and light truck retrofit devices for reducing fuel consumption in a timely, economic, and effective manner. This Phase I preliminary evaluation effort included the selection of a number of the more promising devices for further evaluation in a Phase II test program, as well as a tentative selection of appropriate test organizations and test procedures to be utilized.

An extensive review was conducted of the available descriptive material and test data for representative devices or classes of devices which have been offered for or have made claims of improved fuel economy (reduced fuel consumption) when installed or used. In addition, each such device or class was analyzed with regard to possible operational effectiveness modes and concomitant side effects.

In general, there are insufficient test data to adequately quantify the fuel economy of vehicles before and after installation of a given device on an acceptable, controlled, driving cycle or other meaningful test basis. Where these data are provided, they are often of such nature that they could have been significantly affected by the condition of the test vehicle prior to addition of the device (e.g., could have been out of tune, etc.) or by the driving habits of the test driver (e.g., on city driving routes, accumulated mileage tests, etc.). In addition, most data provided are for a single car, thereby preventing extrapolation of measured effects to other makes and models of vehicles.

Therefore, analyses of the theoretical effect of a given device's claimed or observable operational features were necessarily relied on heavily in evaluating the relative potential of a device for improving fuel economy.

The following are brief highlights summarizing the major findings of the Phase I analysis and preliminary evaluation activities. For purposes of convenience, estimated fuel economy improvement potential is described according to the following definitions:

a. Negative (decreased fuel economy)
b. Negligible (from no change to 4% improved fuel economy)
c. Modest (from 5% to 14% improved fuel economy)
d. Substantial (15% or greater improved fuel economy)

The evaluation estimates presented below are necessarily limited to and based on the types and quantity of the test data made available, as well as the ability to correlate and estimate the impact of the device's operation using basic principles of spark ignition engine operation.

1.1 SPECIFIC RETROFIT DEVICES/CLASSES

1.1.1 Carburetors

a. Of the 16 specific carburetors examined, 4 were deemed to have sufficiently meritorious operating principles and/or test data to warrant further consideration at this time. These carburetor systems were of the type permitting "lean" operation (air-fuel ratio (A/F) = 18 to 20) and included: Electrosonic Fuel Induction System, Ultrasonic Fuel System, Dresserator System, and the Ethyl carburetor.

b. The other carburetor concepts either (a) have operating principles which may indeed improve fuel economy but which have not been adequately verified by test data or which are interrelated with specific driving cycle characteristics (e.g., cold starts, engine warmup, decelerations, etc.) to such an extent that further substantiating information is required from the developer; (b) have no substantiation in operating principle or data; or (c) which do not, in fact, exist for evaluation purposes.

c. It is estimated that carburetors permitting "lean" operation have the potential for "modest" improvements in fuel economy due to lean operation alone (in the order of 5% to 6%, compared to nominally stoichiometric operation). In addition, improvements to reduce "choked" operation requirements and/or to improve atomization or vaporization during engine warmup could further improve fuel economy. Finally, the ability to advance spark timing while maintaining NO_x levels equivalent to those obtained with stoichiometric or rich operation with retarded timing can result in fuel economy improvements (e.g., ~15% improvement at NO_x levels of ~2 gm/mi).

1.1.2 Carburetor-Related Devices

a. The carburetor-related devices evaluated were hollow needle screws to be used as replacements for the standard idle mixture adjusting screws of a carburetor (Econo-Needle, Wyman Valves). The hollow screws permit some outside air to bleed into the air-fuel mixture, thereby providing a somewhat leaner air-fuel ratio during idle and deceleration (high manifold vacuum conditions). The principal result is a reduction in CO and, to a lesser extent, HC; oxides of nitrogen (NO_x) tend to increase somewhat. Similar reductions in HC and CO might be achieved simply by resetting the standard idle mixture screws.

b. Although improved fuel economy is claimed by the manufacturers, the available data (from 8 tests; 5 vehicles) is mixed with a spread from a 4% decrease to a 4% increase in fuel economy. On this basis, the fuel economy improvement potential of such devices is estimated to be "negligible."

1.1.3 Atomizers

1.1.3.1 Acoustic Atomizers

a. Fuel atomization by high frequency (ultrasonic) vibrations is a feature of several devices designed to improve fuel economy or emissions. These include the Electrosonic Fuel Induction System, the Ultrasonic Fuel System, the Echlin NO_x retrofit device, and the Post Carburetor Atomizer (PCA). Of these, only the PCA is designed as a separate unit for retrofit as a fuel economy device.

b. The PCA device mounts between the carburetor and the inlet manifold. In principle, it is the same as the atomizer unit of the Electrosonic Fuel Induction System. Lack of test data prevents a complete assessment of the potential of this device. As a class, however, ultrasonic atomizers appear to have some potential for fuel economy improvement, primarily as a consequence of providing improved vaporization of the fuel under cold or warmup engine conditions. This may be significant, since trip statistics indicate that a preponderance of individual car trips are completed with the engine still in the transient warmup phase.

1.1.3.2 Mechanical Atomizers

a. Four specific mechanical atomizers were examined. Three were screen configurations (Hydro-Catalyst, Spartan II, and the Vaporizer) and one was a deflector plate (F.O. Wieseman). The screen systems function so as to provide a large surface area for fluid impingement and collection to enhance vaporization, while the deflector plate imparts a swirl to the flow to improve vaporization and atomization by turbulence and mixing.

b. Substantive comparative test data for mechanical atomizers are meager. Engine dynamometer tests of the Hydro-Catalyst device at the University of Michigan indicated that the device had a negative effect on fuel economy at simulated steady-state driving conditions (from 25 to 70 mph). Tests of a 1973 vehicle with the Hydro-Catalyst device (by Scott Laboratories using the 1972 Federal Test Procedure) indicated a 34% improvement in fuel economy over the same vehicle without the device. However, the ignition timing was advanced seven degrees as compared to the stock vehicle setting without the device; such an advance in timing would be expected to substantially improve fuel economy. Based on these data, it is estimated that mechanical atomizers would have a "negligible" effect on fuel economy.

1.1.4 Lean-Bleed Systems

a. Lean-bleed systems or devices are those which admit or "bleed" additional air (through the positive crankcase ventilation (PCV) valve line or directly into the intake manifold) during idle, deceleration, or low-speed operation. Representative of these are the Adaks Vacuum Breaker, an Albano Industries device (marketed under several names, including Air Jet, Mini-Turbocharger, etc.), the Ball-Matic device, the Pollution Elimination Device (PED), and the STP Modulating Air Bleed. Many of these lean-bleed systems were originally marketed as devices for reducing exhaust emissions. However, recent claims have stressed fuel economy benefits as well; greater than 10% improvement in many cases and up to 25%.

b. There is wide variability in the results of available fuel economy and emissions tests. Lean-bleed devices as a class do appear to be consistently beneficial in reducing CO emissions but are erratic with respect to HC and NO_x emissions. The greatest improvements in fuel economy and emission reductions would be expected on pre-controlled cars where rich carburetor mixture settings would benefit by the technique of leaning. On an overall basis, the available data suggest that such devices would result in "negligible" fuel economy improvements.

1.1.5 Vapor Injectors

a. Vapor injectors usually consist of a container holding a water solution of alcohol plus other organic additives. The fluid is evaporated or entrained as fine droplets by air taken in through a valve in the top of the container and passed through an aeration device inserted in the liquid. A combination of vapor and an aerosol mist is injected into the intake manifold, usually through the PCV valve line, with the motive force due to the differential pressure between ambient and manifold vacuum.

b. Improvements in fuel economy up to 20% are claimed by the manufacturers of these devices, due to better atomization of fuel droplets and more even distribution of the fuel-air mixture to the engine cylinders. It is also postulated that the presence of water vapor in the fuel charge tends to suppress flame velocities and temperatures, thus avoiding energy losses due to auto-ignition and knocking.

c. The available fuel economy test data (from EPA, California Air Resources Board, and University of Michigan tests) indicate vapor injectors have a minimal effect on fuel economy; any slight improvements that might be noted would likely be caused by the leaning of the intake mixture ratio by the injected air, since the typical vapor injector injects only a mixture of vapor to gasoline of about 0.4%.

1.1.6 Fuel Modifications

a. Modern major brand gasolines already incorporate detergent and/or dispersant additives. The available fuel economy data for the 14 specific gasoline additives examined in this study indicate that they would have a negligible effect on fuel economy when compared to such existing modern gasolines.

b. With regard to fuel mixtures, a number of combinations were considered: gasoline/alcohol, gasoline/water, and gasoline/water/alcohol. In each case, the available vehicle fuel economy data have shown no more than "negligible" increases, while there are some instances of fuel economy decreases due to rough engine operation, misfiring, etc. Although there is some engine dynamometer test data to indicate the potential for "modest" increases in fuel economy with gasoline/water mixtures, at the present state of development for retrofit applications, it is estimated that such fuel mixtures would have a "negligible" effect on fuel economy.

1.1.7 Inlet Manifolds

a. Retrofit inlet manifolds are available with reduced flow cross-sectional areas which increase the flow velocity of the fuel-air mixture in the manifold and which should improve fuel distribution.

b. The available inlet manifold test data present a somewhat mixed picture. Offenhauser data indicate fuel economy improvements in the "negligible" range (3% to 4% in federal test procedures (FTP) tests), while Edelbrock data indicate "modest" to "substantial" improvements (9% in FTP tests, 16% to 18% in dynamometer tests and street driving). Because of the possible strong effects of the inlet manifold on fuel economy during cold start, warmup, and low speed operation, it is estimated at this time that inlet manifold retrofits may have the potential for "modest" fuel economy improvements.

1.1.8 Fuel Pressure Regulators

Pressure regulators, which are advertised to prevent excess fuel pressure from blowing the needle valve in the float bowl off its seat, are estimated to result in "negligible" improvements in fuel economy. This estimate is based on University of Michigan tests of one such device.

1.1.9 Ignition Systems

a. The conventional ignition system is generally quite adequate for purposes of combustion-initiation unless or until the system components (plugs, points, etc.) wear out or are otherwise affected by operational constraints (plug deposits, etc.). The use of leaner mixtures, dilute mixtures (e.g., from internal or external EGR), and reduced choking durations and mixture strengths, however, can result in operating conditions where the conventional ignition system is marginal. The use of both capacitive discharge (CD) and electronic inductive ignition systems should be beneficial in these instances, particularly with regard to driveability considerations. However, for vehicles which are well maintained and have tune-ups at recommended intervals (before incipient malfunction), it is estimated that both CD and electronic inductive ignition systems would result in "negligible" improvements in overall fuel economy.

b. However, recognizing that many owners do not properly maintain their vehicles, the longer service life capability of CD and electronic inductive ignition systems suggest that "modest" improvements would result from their use. This would be particularly true for vehicles with lean air-fuel ratio settings which would be more prone to cylinder misfire with deterioration of ignition system voltage. On an overall basis, then, such ignition systems are rated in the "modest" category.

c. There are some ignition systems which merely replace existing components of the conventional system and are estimated to result in a very limited or "negligible" fuel economy improvement potential.

d. There are, in addition, some "unconventional" systems, sometimes called "ignition bridges," which are added to conventional ignition systems with claims of improved performance. Analysis of their effects on fuel economy has not been possible, but University of Michigan tests of one such device indicate it should be placed in the "negligible" category.

1.1.10 Emission Control Retrofit Systems

Retrofit systems designed for emission control were known to have possibly adverse effects on fuel economy but were examined in this study in order to place their characteristics in perspective with those of devices claimed to improve fuel economy. NO_x control systems such as vacuum-spark-advance-disconnect (VSAD) and exhaust gas recirculation (EGR) have fuel economy penalties ranging from 3% to 10%. Carburetor-plus-distributor retrofits for HC and CO control have a small fuel economy penalty (~2%). Oxidation catalyst retrofits (for HC and CO control) can result in fuel economy penalties up to 2%.

1.1.11 Drivetrain Components

a. Radial tires, in particular the steel-belted variety, are estimated to have the potential for "modest" improvements in fuel economy. The actual improvement realized may vary with the type of driving conditions and tire age.

b. In the area of transmissions, special 4- and 5-speed range automatic transmissions tested in large van-type trucks by the U.S. Auto Club demonstrated ~11% fuel economy improvement when compared to manual-transmission-equipped vehicles. However, this type of transmission is not planned for production for passenger car use.

c. Of course, engine speed (rpm) reduction at a given vehicle speed (mph), as effected by changing the rear axle gear ratio or by adding an overdrive unit, is well known to result in reduced fuel consumption. In highway driving operation, both techniques can result in "substantial" fuel economy improvements. When city traffic driving is taken into account, however, such fuel economy improvements are estimated to be reduced to the "modest" category. In addition, merely changing the rear axle gear ratio will result in reduced acceleration performance and hill-climbing ability. The overdrive unit permits down-shifting to normal gear ratios for better acceleration in city traffic driving. In vehicles equipped with a torque converter, a portion of the potential fuel economy benefit of an overdrive unit or axle ratio decrease is lost due to increased torque converter slip.

1.1.12 Drag-Reduction Devices

Any reduction in aerodynamic drag would, of course, be beneficial with regard to reducing fuel consumption, since power and fuel required to overcome drag are reduced. However, the magnitude of the benefit is dependent on the vehicle speed. For example, at low speeds, the rolling resistance is much higher than aerodynamic drag; at ~40 mph, the two forces are nearly equal; at ~70 mph, the air drag is 2 to 3 times higher than the rolling resistance. It is estimated that drag-reduction devices could result in "modest" fuel economy improvements during highway driving but that their effect would be "negligible" in city traffic or other low-speed driving.

1.1.13 Driver Aids

The effect of driver aids, such as vacuum gages, miles-per-gallon meters, cruise controls, etc. are felt to be indeterminate with respect to fuel economy improvement. Some drivers might have "negligible" improvements while other very careful drivers may be able to achieve "substantial" improvements if the device enables them to change their driving habits from the "hotrod" category to that of totally fuel economy oriented.

1.1.14 Flexible Cooling Fans

A comparison of conventional and retrofit flex-fan power requirements indicates essentially no difference in power requirements until the engine speed exceeds approximately 3000 rpm (~ 84 mph). At 5000 rpm, the flex fan requires ~3 HP less than the conventional fan. On this basis, it is estimated that retrofit flex fans would provide fuel savings up to 3%, but at engine speeds well above the normal driving range.

1.1.15 Valve Timing

Although claims are made of fuel economy improvements with retrofit camshafts or variable-cam-timing devices, the data from available vehicle tests indicate negative or insignificant effects on fuel economy.

1.1.16 Engine Tuneups

Engine tuneups are recognized as a requirement in order to avoid fuel economy degradation which results from ignition system wearout, carburetor deposits, etc. Statistical data to quantify average fuel economy improvements from tuneups are not available. Data from one car test indicated ~10% fuel economy improvement over the 30 to 70 mph speed range after a tuneup. In a representative test of the 1957 through 1970 California passenger car population by the California Air Resources Board, 300 vehicles were given special tuneups to reduce their exhaust emissions to the practical minimum, tested again immediately after the tuneup, and tested again after 6 months of service. The average fuel consumption decreased by 5% immediately after the tuneup. At the end of 6 months, the fuel consumption was still 3.7% less. On this basis, tuneups are rated in the "modest" category, although it is recognized that the amount of improvement obtained for a given car would be a function of its relative state of maintenance and mileage since it was last tuned.

1.1.17 Compression Ratio Increases

Although "modest" fuel economy improvements can be realized by increasing the engine compression ratio (by shaving the head or by replacing the pistons), it is not recommended, because it would require higher octane gasoline and the emissions of HC and NO_x could be increased somewhat.

1.1.18 Exhaust-Related Systems

a. Based on limited test data, tuned exhaust systems are estimated to have the potential for "modest" improvements in fuel economy. This is due to the combination of reduced exhaust backpressure (and pumping losses) and improved cylinder scavenging effects.

b. Dual exhaust systems are estimated to result in "negligible" (1% or less) fuel economy gains; backpressure reductions are not significant.

c. Exhaust cutouts, which afford maximum backpressure reductions, are estimated to result in "modest" fuel economy gains at high speed and load conditions. However, this approach is not recommended as it is illegal in some states because of noise effects.

d. Exhaust-gas-driven turbochargers are estimated to result in small (2% to 3%) fuel economy losses when added to a stock engine in a vehicle. If the engine were also replaced with one ~30% smaller in displacement, then a "substantial" improvement in fuel economy could be projected. However, this would be a very expensive method of "retrofitting."

1.1.19 Engine Oil, Oil Additives, and Filters

a. It is difficult to support the fuel economy improvement claims of up to 20% as made by manufacturers or users of the engine oil and additive examined in this study. For example, a 20% improvement in fuel economy corresponds roughly to a 3.5% improvement in engine thermal efficiency, a quantity equal to about half the total loss due to mechanical friction in the engine. Other sources have postulated that improved oil formulations could contribute to as much as 6% to 10% fuel economy improvements. On this basis, it is estimated that "modest" improvements "may be possible" with improved engine oils or additives.

b. The advanced engine oil filter examined in this study is estimated to result in minimal effects on fuel economy, regardless of its efficacy as an oil filter. While it certainly could prevent performance degradation due to wearout of parts dependent on lubrication (cylinders, cylinder walls, etc.) and could extend engine operating life on that basis, its fuel economy improvement impact would thus be limited to those factors affected by lubricated component wear rate, which is judged to be indeterminate for purposes of the present study.

1.1.20 Tampering with Emission Control Systems

It has been suggested that some vehicle owners might have their emission control systems (ECSs) altered or tampered with in an effort to improve fuel economy, even though this is prohibited by law. The Environmental Protection Agency (EPA) conducted a 10-car program (1973 and 1974 model years) to examine possible effects. When such adjustments were made by private garages, there was an average decrease in fuel economy of ~3.5%. Only 4 out of 13 cases achieved minor improvements in fuel economy.

1.2 RECOMMENDATIONS AS TO FURTHER TESTING AND EVALUATION REQUIREMENTS

1.2.1 "No Additional Testing Required" Category

a. The available technical data, test data, and/or theoretical background information were considered sufficiently adequate so as to negate a requirement for testing in the present program for:

1. Overdrive units
2. Rear axle ratio changes
3. Turbocharger plus smaller engine installations
4. Radial tires
5. Multispeed-range automatic transmissions with lockup clutches

b. In the case of tuneups, it is recognized that there is a lack of fleet test data to adequately quantize overall effects of engine tuneups on vehicle fuel economy on a statistical basis. However, it is felt that the beneficial effects of tuneups are sufficiently well recognized and that a test program adequate for this purpose would be sufficiently large (in number of vehicles required) as to be beyond the scope of the Phase II test program.

1.2.2 "Additional Testing Required" Category

a. In the case of all other devices estimated to have "modest" or better fuel economy improvement, it is considered that the test data base is incomplete and inadequate for purposes of properly quantifying the relative impact of each device or device class on fuel economy improvement potential. Indeed, in most cases the devices or classes were rated to have the potential for fuel economy improvement primarily based on their postulated operational features alone. In those cases where these available test data were promising, they were incomplete and/or inadequate with respect to "controlled test" requirements.

b. The evaluation of oil, oil additives, drag-reduction devices, and driver aids disclosed factors which indicated they would not be suitable candidates for the Phase II test program. In the case of special engine oils and/or oil additives, it was felt that simple vehicle comparative tests (with and without the oil or additive) would not be adequate to determine true fuel economy effects or possible adverse effects on parts lubrication, parts wear, etc. Such an evaluation should include extensive dynamometer tests, including mileage accumulation tests, which is beyond the scope of the Phase II test program.

c. The proliferation of passenger car sizes, models, and body shapes would require extensive vehicle tests over closely controlled test tracks and test conditions (wind effects, etc.) in order to properly evaluate the effects of drag reduction devices on fuel economy. Again, these types of tests are not within the scope of the planned Phase II test program.

d. Similarly, an adequate evaluation of the effects of various driver aids (vacuum gages, miles-per-gallon meters, etc.) on vehicle fuel economy would also require many vehicles and many drivers to arrive at a statistically meaningful answer as to fuel economy improvement potential; therefore, evaluation of driver aids is not within the scope of the Phase II effort.

1.2.3 Recommended Devices for Phase II Testing

a. Table 1-1 summarizes the devices recommended for testing in the Phase II test program. These devices are those which were (a) considered to have the potential for fuel economy improvement of 5% or more, (b) required additional confirmatory testing to adequately establish their fuel economy improvement potential, and (c) were available and within the scope of the planned Phase II testing effort insofar as tests with and without the device were considered sufficient to establish their relative merit.

b. In addition to specific single devices, two device combinations are included in Table 1-1:

1. Inlet Manifold and Tuned Exhaust

   The combination of these devices suggests that they might exhibit the greatest combined effect on engine "breathing" (induction, scavenging, and exhaust) and thus might possibly achieve "substantial" fuel economy improvements.

2. Carburetor Plus CD Ignition

   The combination of these devices suggests that they might exhibit the greatest combined effect on air-fuel ratio, charge preparation, and combustion, particularly for vehicles with lean air-fuel ratio settings.

TABLE 1-1. RECOMMENDED DEVICES FOR NEAR-TERM TESTING

- Dresserator Carburetor
- Electrosonic Fuel System[*]
- Acoustic Atomizer (PCA)
- Inlet Manifold
  - Offenhauser or Edelbrook
- MSD Ignition System[**]
- Tuned Exhaust System

- Combinations
  - Inlet Manifold and Tuned Exhaust
  - Carburetor and MSD or PCA and MSD

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[*] Ultrasonic Fuel System is Similar to Electrosonic; not necessary to test both at this time.

[**] An improved capacitive discharge system which provides a multiple spark discharge (MSD).

SECTION 2

INTRODUCTION

2.1 BACKGROUND, OBJECTIVES, AND SCOPE

The recent embargo on petroleum exports to the United States by the oil-producing countries of the Middle East amply demonstrated that automotive fuel shortages in the United States can occur at any time unless and until the United States becomes self-sufficient with regard to automotive fuel needs. As a result, many concerned people have postulated 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 recommending 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. Many conflicting claims have been made regarding fuel economy advantages. In addition, some of the communicants have expressed the opinion that the automotive industry might be "suppressing" the development or use of advanced or novel carburetion techniques in one manner or another.

In addition to carburetors, there has also been a large number of other devices offered for sale as retrofit or add-on units for automobiles and advertised to improve fuel economy (reduce fuel consumption). In most cases, test data to verify the degree of fuel economy improvement claimed have not been immediately available nor technically substantive in nature.

Therefore, the present study was initiated with the objectives of evaluating the potential of used car and light truck retrofit devices for reducing fuel consumption in a timely, economic, and effective manner; of providing the information necessary for the federal government to determine if it should encourage the use of such retrofit concepts; and of offering a plan for DOT to develop any needed additional information.

These objectives were to be met by means of (a) the identification and characterization of retrofit devices, ideas, concepts, and/or fuel modifications which have been postulated to offer meaningful reductions in automotive fuel consumption; (b) the analysis of each such promising device or concept with regard to operational effectiveness modes and resultant fuel economy gains, degree of applicability to the existing vehicle population, and concomitant side effects; (c) an initial comparative evaluation of contending retrofit concepts to identify the most promising concept(s) in terms of effectiveness, applicability, availability, economics, and emissions; (d) the definition of a test plan for experimental verification of selected retrofit devices; (e) a verification test program; and (f) a final evaluation of relative merit with regard to fuel economy improvement potential based on test program results.

The study was limited in scope to those retrofit devices/concepts/techniques which were readily identifiable and already available or which could reasonably be expected to be available in the immediate future. Thus, mere ideas or approaches which have had little or no development activity to bring them to fruition were excluded from consideration. In the main, the concepts included in the study are those for which a hardware item or system has been built or is known to be offered for sale.

The program was divided into two phases to aid in implementation. Phase I, the analytical and preliminary evaluation phase, encompassed items (a) through (d) above, and this report presents the results of these Phase I activities. Phase II, the testing and final evaluation phase, will be reported separately after all test activities have been completed.

2.2 ACQUISITION OF RELEVANT DATA

These data and information reported herein were acquired and/or developed between 1 May 1974 and 15 October 1974. Much of the information related to retrofit concept identification and characterization was provided to DOT by device inventors, developers, or by Congressmen who had received the data from interested parties. Some concepts were also identified from sales brochures, catalogs, advertisements, and newspaper or magazine articles.

Substantive test data for many of the retrofit devices were obtained from the EPA (Ann Arbor, Michigan) and the California Air Resources Board (CARB) who had performed vehicle tests to determine the effects of the devices on exhaust emissions. In addition, Professor David E. Cole, University of Michigan, provided fuel economy test data for 11 different aftermarket add-on devices which were tested at the University of Michigan Automotive Laboratory on an engine dynamometer.

During the course of the study, many contacts were made with various device manufacturers or developers to obtain characterization information and test data.

2.3 ORGANIZATION OF THIS REPORT

All retrofit concepts/devices were categorized by major groups and subgroups to facilitate activities related to characterization and analysis. Table 2-1 summarizes the basic retrofit category groups, and Table 2-2 summarizes the basic retrofit types or subgroups considered.

The organization of this report follows the group and subgroup breakdowns of Tables 2-1 and 2-2, in consecutive order as listed.

Within each major section or substantive area of the report, the material is organized as follows:

a. Brief introductory statement
b. Short theoretical discussion of how the device or class of devices are postulated to operate and how much fuel economy improvement would be anticipated on this basis
c. A detailed discussion of each major device or, in the alternative, a discussion of the class of devices where many devices are identical or similar in nature (Factors discussed, as appropriate, are summarized in Table 2-3)
d. Tabular summaries of evaluation factors
e. Short summary for the device or class of devices

TABLE 2-1. BASIC RETROFIT CATEGORIES

- Fuel/Air Metering
- Ignition
- Emission Control
- Drivetrain
- Vehicle Structure
- Auxiliaries and Accessories
- Operational and Adjustment Techniques
- Exhaust-Related Systems
- Miscellaneous

TABLE 2-2. BASIC RETROFIT TYPES

Fuel/Air Metering

○ Carburetors and Carburetor-Related
○ Atomizers
○ Lean-Bleed Systems
○ Vapor Injectors
○ Fuel Modifications
○ Inlet Manifolds
○ Fuel Pressure Regulators
○ Fuel Pre-Agitators

Ignition

○ Capacitive Discharge
○ Electronic Inductive
○ Spark Plug
○ Ignition Bridges

Emission Control

○ Spark-Control Related
○ EGR-Related
○ Carburetor Plus Distributor Retrofit
○ Catalyst Systems

Drivetrain

○ Tires
○ Transmissions
○ Overdrive Units
○ Rear Axle and/or Gear Ratio Changes

Vehicle Structure

○ Drag Reduction

Auxiliaries and Accessories

○ Driver Aids
○ Cooling System

Operational Adjustment Techniques

○ Valve Timing
○ Compression Ratio
○ Tuneups

Exhaust Systems

○ Tuned Exhaust Headers
○ Dual Exhaust Systems
○ Exhaust Cutout
○ Turbochargers

Miscellaneous

○ Engine Cleanup
○ Engine Oil and/or Additive
○ Removal of Emission Control Systems

TABLE 2-3. FACTORS CONSIDERED IN EVALUATION OF FUEL ECONOMY RETROFIT DEVICES

- Degree of Fuel Economy Improvement
- Effect on Exhaust Emissions
- Type of Data Available
- Source and Reliability of Data Base
- Retrofit Device or "Kit" Content and Physical Characteristics
- Compatibility with Mass Production
- Potential Availability in Near Future
- Applicable Vehicle or Engine Models
- Installation Requirements (Including Necessary Facilities)
- Installation Time
- Cost to Consumer for Installation
- Maintenance Requirements
- Effect on Vehicle Power and Acceleration Performance

SECTION 3

FUEL-AIR METERING SYSTEMS

The largest class of retrofit devices/concepts considered is that of fuel-air metering systems. As defined and utilized herein, this class of devices includes all those whose design and/or operational features impact in any manner upon the type, quantity, or quality of the fuel-air charge as delivered to the engine cylinders. Table 3-1 summarizes the specific device/concept subgroups evaluated, and Table 3-2 summarizes the specific carburetors examined during the study. These carburetors are discussed first in this section.

3.1 CARBURETORS

The following discussion responds, at least in part, to the parties interested in fuel economy improvement via carburetion improvements. The purpose of this section 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 is first discussed in terms of the carburetor design, its operation, and its basic limitations. Next, current carburetor improvements being developed by the auto industry for near-term implementation are delineated. Then, a number of selected, specific carburetors currently being produced or discussed in this country are examined as to their status. This examination includes: the principal advantages claimed, principles of operation and construction, available substantive data on fuel economy effects, disadvantages, current development status, costs, etc.

TABLE 3-1. FUEL-AIR METERING SYSTEMS

Conventional Carburetor

- Construction and Operation
- Inherent Limitations
- Baseline for Evaluating Other Approaches

Other Publicized Carburetors

Carburetor-Related Devices

Atomizers

Lean-Bleed Systems

Vapor Injectors

Fuel Modifications

Inlet Manifolds

Fuel Pressure Regulators

Fuel Pre-Agitators

TABLE 3-2. OTHER PUBLICIZED CARBURETORS

Electrosonic Fuel Induction System
Ultrasonic Fuel System
Cal-Tech Super Carburetor
Woodworth Carburetor
Kendig Carburetor
Arpaia Fuel Injection Carburetor
Dresserator System
Fish Carburetor
Gelb Digital-Controlled Carburetor
Pogue Carburetor
Fressenden Carburetor System
Vaporator
Vapipe
Graybill VMM Injector
Ethyl Carburetor

3.1.1 The Conventional Carburetor

The following discussion 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 here.) For the reader interested in further details, or in the specifics of the large variety of carburetors in use in this country, Refs. 3-1 through 3-3 are recommended reading. For readers less familiar with automotive engine operation, the following paragraphs present a brief synopsis of spark ignition engine characteristics.

3.1.1.1 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 (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

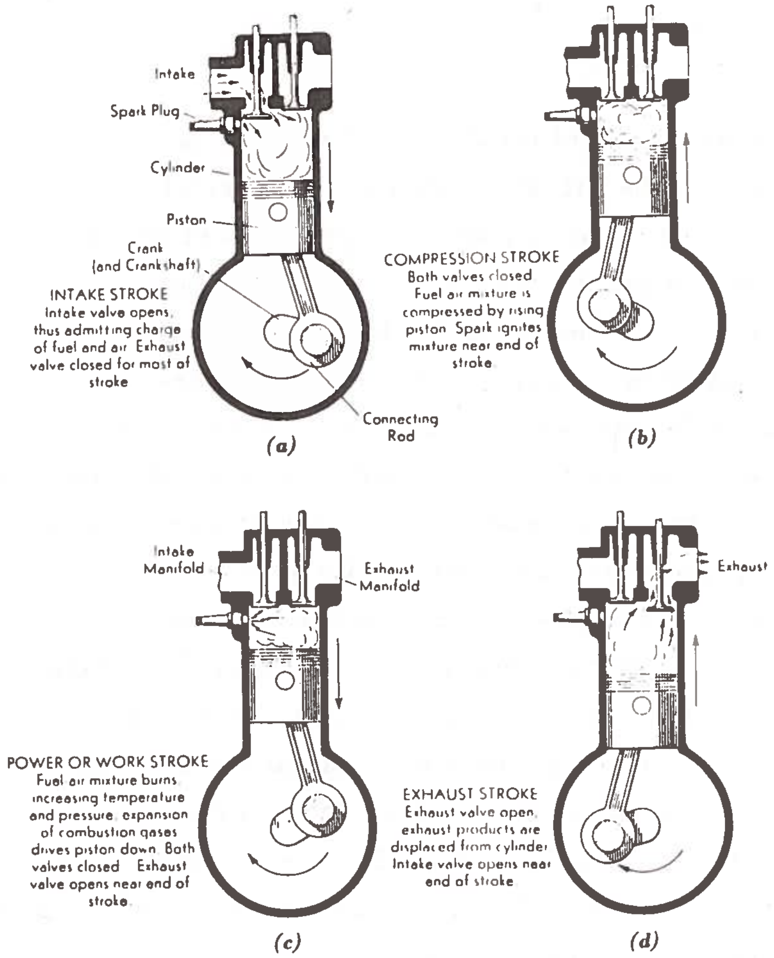

Figure 3-1. The Four-Stroke Spark Ignition (SI) Cycle (Four strokes of 180 degrees of crankshaft rotation each, or 720 degrees of crankshaft rotation per cycle) (Ref. 3-1).

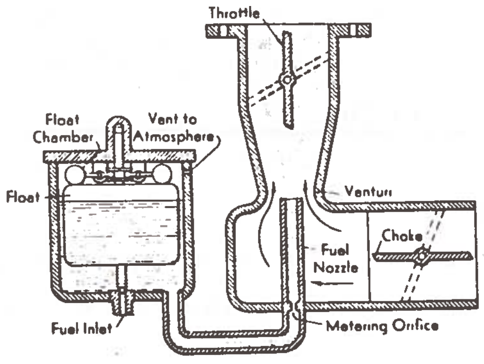

Figure 3-2. Elements of a Simple Updraft Carburetor (Ref. 3-1).

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.

The "choke" enables the engine to receive an additional amount of fuel (a "rich" mixture) for starting when the engine is cold. Closing the

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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.

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.

3.1.1.2 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, warmup, and wide-open throttle (WOT) 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)

3.1.1.2.1 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 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

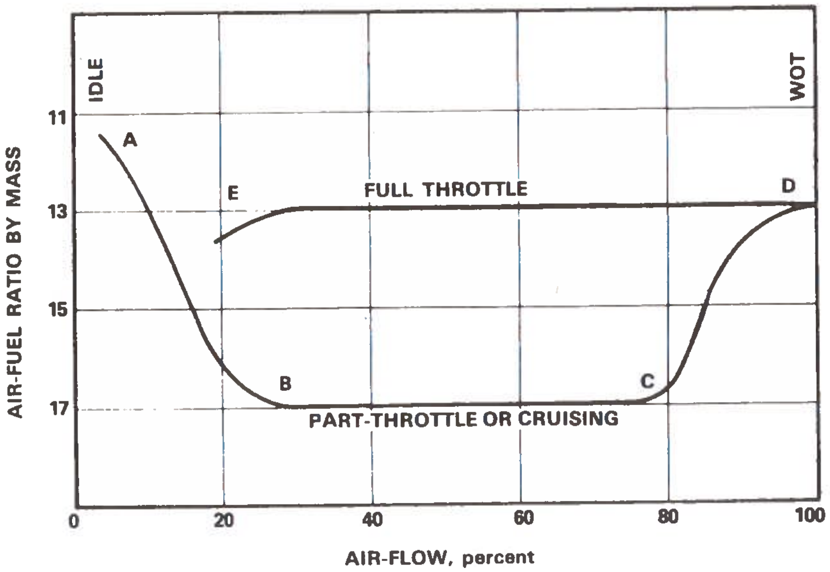


Figure 3-3. Air-Fuel Ratio Required by a Spark Ignition Engine at Various Air Flow Rates (Ref. 3-2)

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.

3.1.1.2.2 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.

3.1.1.2.3 High Loads

Under high load conditions, when the throttle valve is opened 75% 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.

3.1.1.2.4 Transient Mixture Requirements

The principal transient conditions of operation are cold starting, warmup, 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 (an A/F of 1:1 may be required). This very rich mixture is obtained by the use of a choke valve.

b. Warmup. During engine warmup, a rich air-fuel ratio is required, but the degree of richness must be progressively reduced during the warmup 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.

3.1.1.3 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.

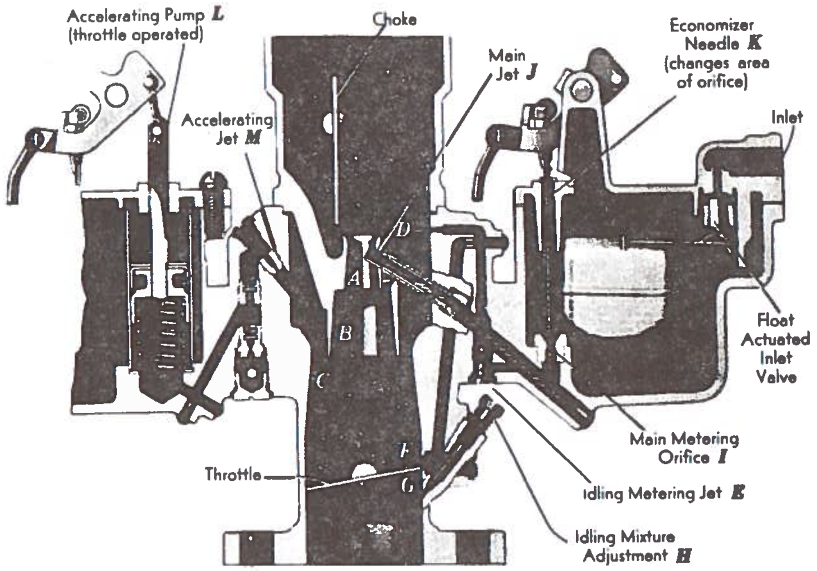


Figure 3-4. Carter Downdraft Triple-Venturi Carburetor with High-Load Enriching Device (Ref. 3-1).

3.1.1.3.1 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 tube (as compared to the metering orifice, I), 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, 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.

3.1.1.3.2 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.

3.1.1.3.3 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.

3.1.1.3.4 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.

3.1.1.4 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,

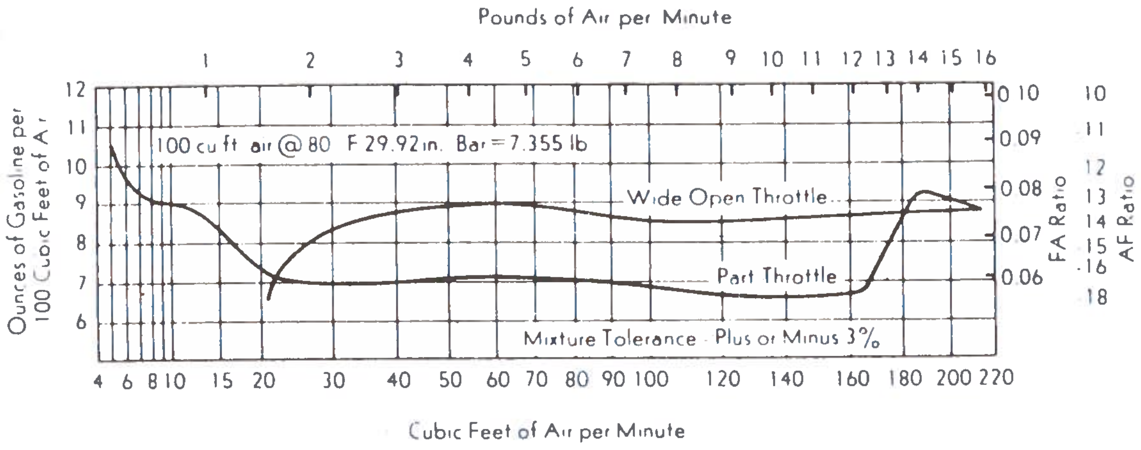


Figure 3-5. Performance Test of Chrysler Corporation Carburetor (Ref. 3-1).

and (at part throttle) a liberal amount of exhaust residual. This departure from ideal conditions affects power, driveability, and fuel economy.

3.1.1.4.1 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% 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% reduced the brake specific fuel consumption (BSFC) by 16% in this case.

3.1.1.4.2 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 towards the front

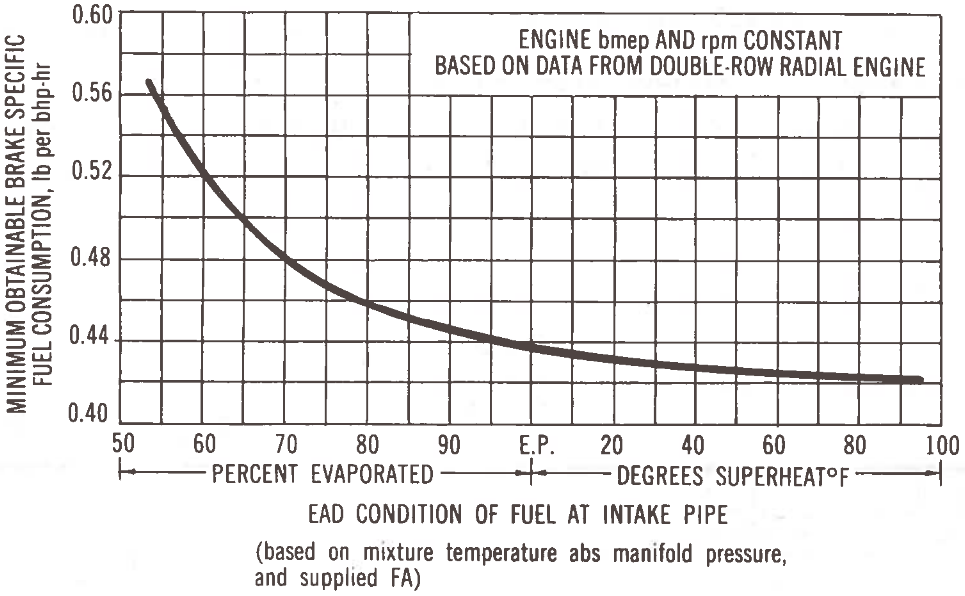


Figure 3-6. Example of Typical Correlation of Minimum Obtainable BSFC with Equilibrium Air Distillation of Fuel (Curve shown is typical of that found with large radial engines under cruising-power conditions, but is greatly influenced by engine design and operating conditions.) (Ref. 3-1)

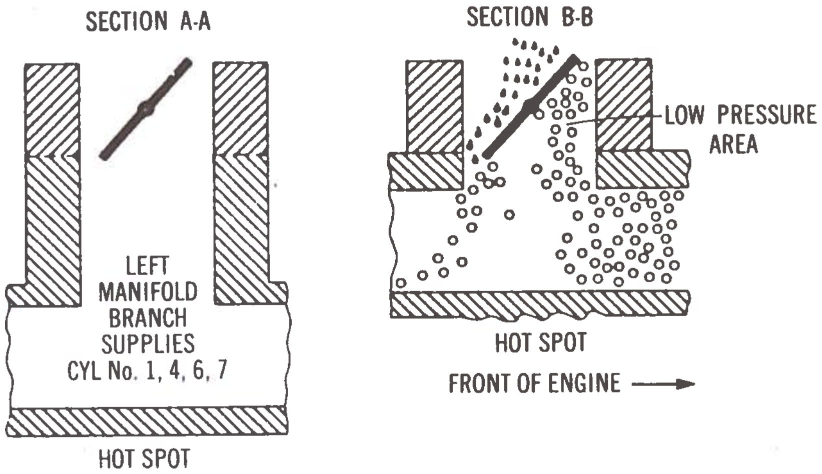
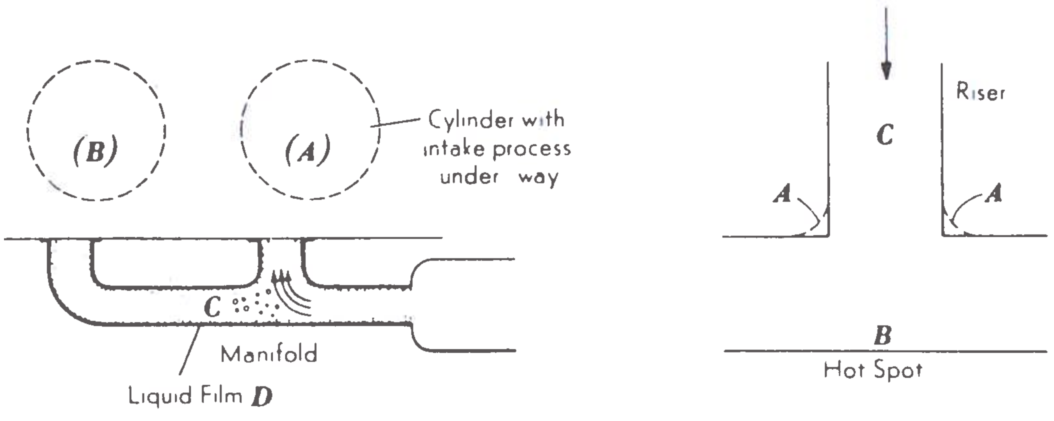


Figure 3-7. Cross Sections Through Intake Manifold of V-8 Engines (Showing different heights of risers and throttle in worst position for distribution) (Ref. 3-1).

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. 3-1).

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 8-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. 3-4).

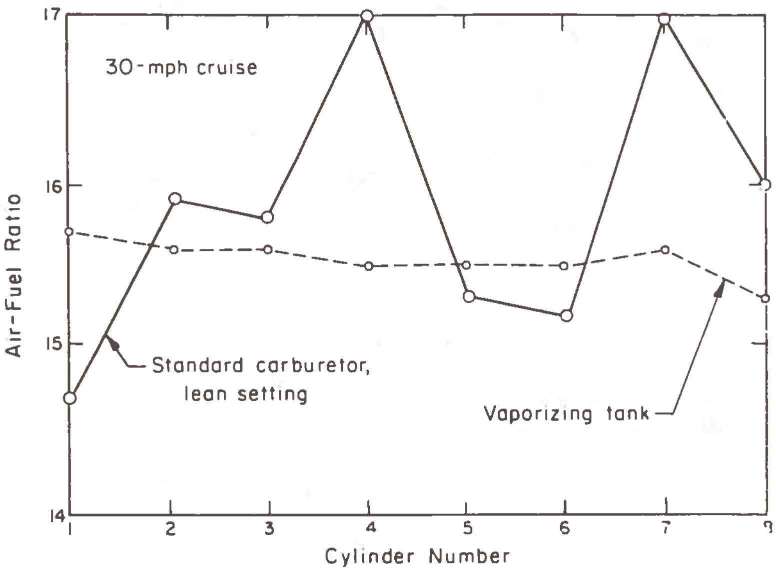


Figure 3-9. Geometric Distribution of Air-Fuel Ratio for Carbureted and Vaporized Fuel in an 8-Cylinder Engine (Ref. 3-4).

Similar data for a 6-cylinder engine are 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. 3-6). These data (Figures 3-11 and 3-12) are for one engine

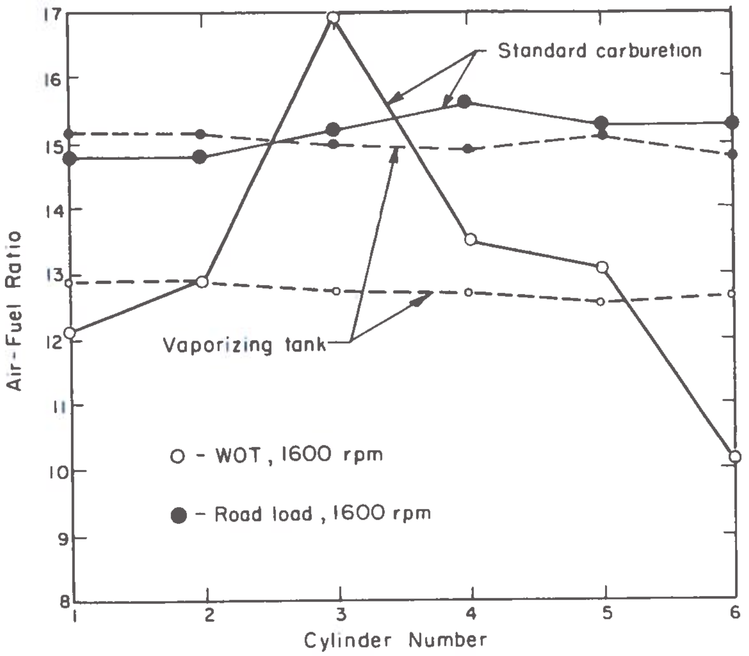


Figure 3-10. Geometric Distribution of Air-Fuel Ratio for Carbureted and Vaporized Fuel in a 6-Cylinder Engine (Ref. 3-6).

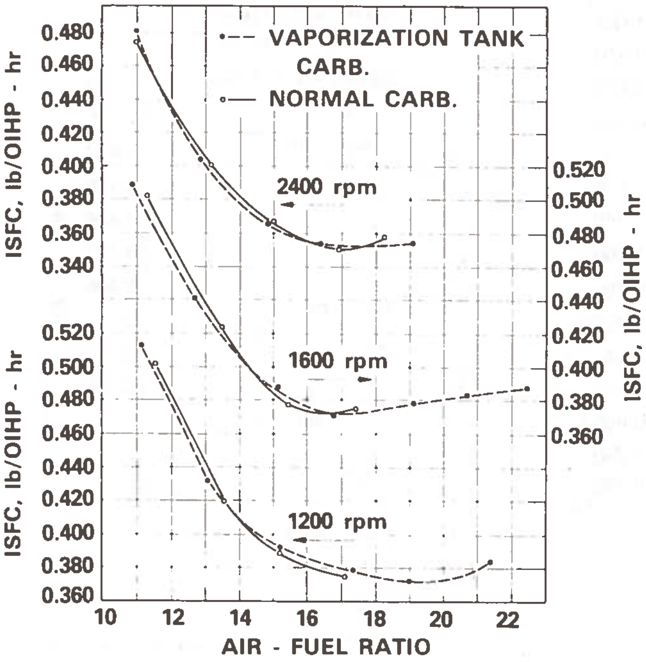


Figure 3-11. Effect of Air-Fuel Ratio on Indicated Specific Fuel Consumption at WOT — Tank Versus Normal Carburetion (Ref. 3-6).

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

3.1.1.4.3 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 6% richer than the lean limit; it was formerly 12% above the lean limit. 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.

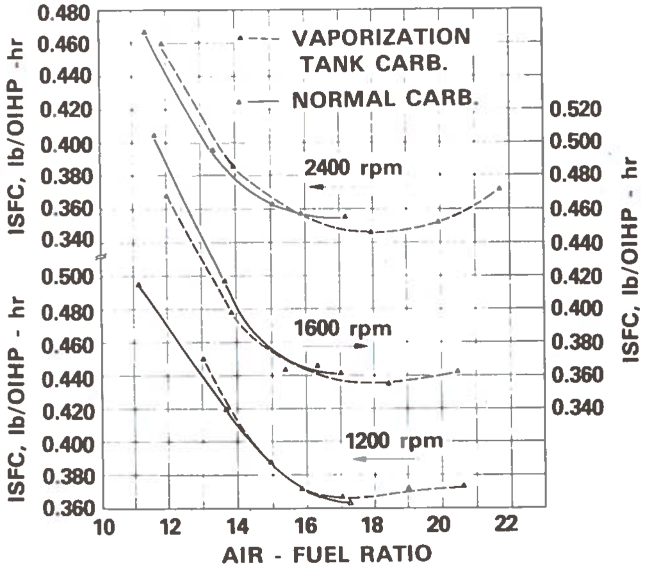


Figure 3-12. Effect of Air-Fuel Ratio on Indicated Specific Fuel Consumption at Road Load — Tank Versus Normal Carburetion (Ref. 3-6).

3.1.1.4.4 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 consumption decreases as the air-fuel ratio increases

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

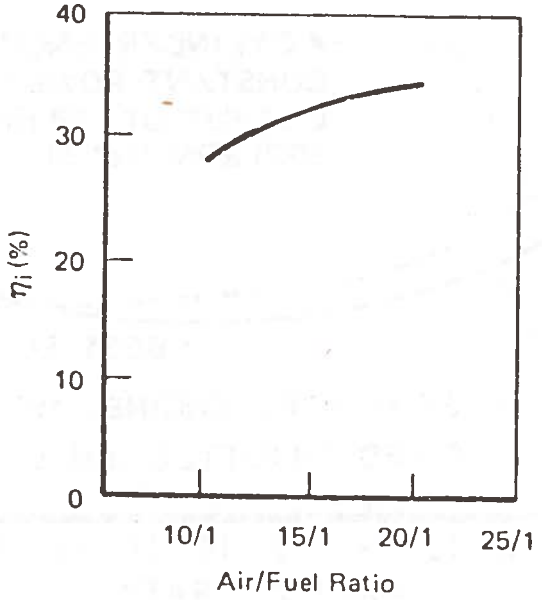


Figure 3-13. Effect of Air-Fuel Ratio on Indicated Thermal Efficiency at Fixed Compression Ratio (Example Only)

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 6-cylinder engine. The best economy was obtained at a lean A/F of 16.4. From this value up to the lean misfire limit (A/F = 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 4-cylinder engine (Figure 3-14), the specific fuel consumption continued to decrease up to A/Fs 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.

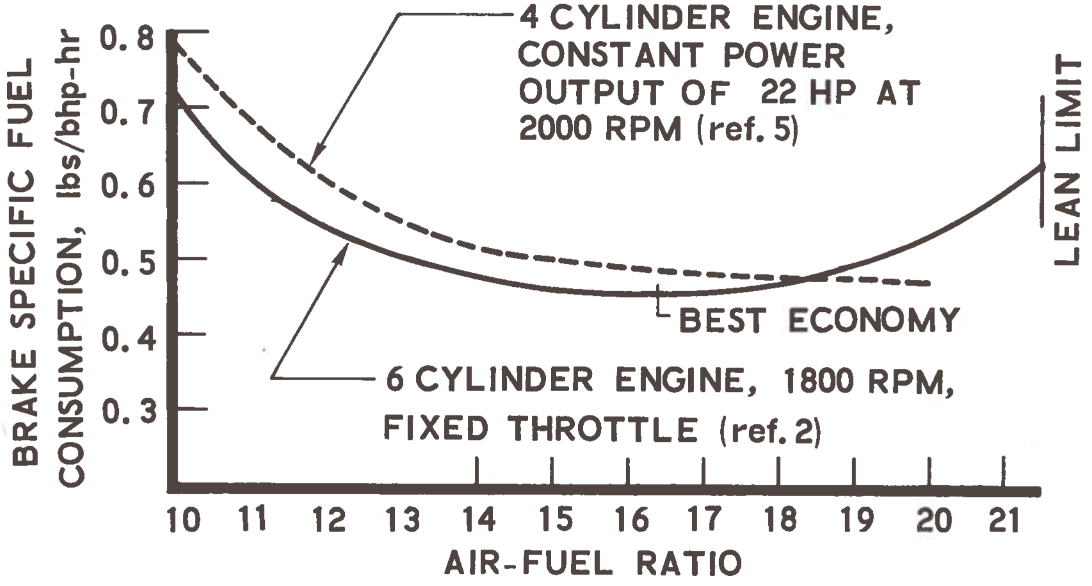


Figure 3-14. Effect of Air-Fuel Ratio on Specific Fuel Consumption

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.

3.1.1.4.5 Overall Effects

Unfortunately, there are little direct data which adequately quantify the overall effects of incomplete atomization, vaporization, and maldistribution on fuel economy in conventional carbureted spark ignition engines. Reference 3-6 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 are little data in the available literature. The test data shown in Figure 3-14 indicate approximately a 6% improvement in operating at an A/F of 20 instead of 15. Schweitzer (Ref. 3-7) indicates a postulated improvement of 7% in fuel economy by operating at an A/F of 22 instead of 15. However, as compared with emission-controlled vehicles operating with rich mixtures, estimates of fuel economy improvments (at the same emission levels) for lean-mixture operation range up to 30% (Ref. 3-7).

3.1.2 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 modififications 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 ($A/F > 20$) for control of oxides of nitrogen, in combination with the potential for fuel economy improvement. In addition to their in-house carburetor developments, the automakers are examining the concepts of others. For example, the Ford Motor Company is evaluating the Dresserator carburetor, 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.

3.1.3 Status of Other Publicized Carburetors

The following pages 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 are 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 are insufficient 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.

3.1.3.1 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 3-15). 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.

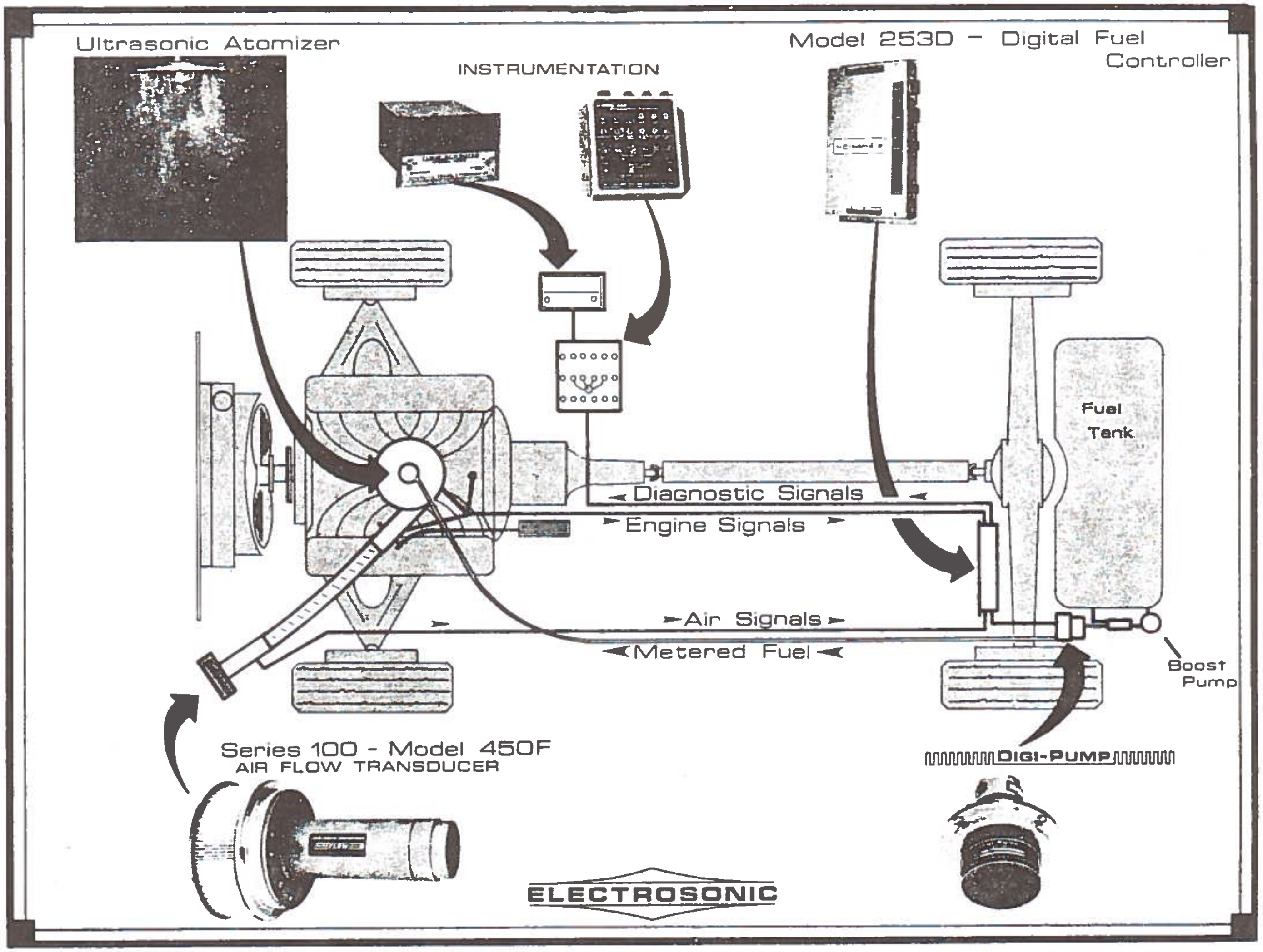


Figure 3-15. Electrosonic Fuel Induction System (Ref. 3-11)

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% (Ref. 3-8), but substantiating data are lacking.

The device has been tested on a number of cars, with nominal A/F 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 A/F setting of 17 as recommended by the manufacturer for minimum emissions. No fuel economy tests were run (Ref. 3-9), but the emission results in grams/mile (1975 CVS) were as follows:

	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. 3-10), 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% being achieved. However, details of the test duty cycle used, etc., were not reported (Ref. 3-11).

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 Electronsonic 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. 3-11).

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 20% to 25% improvement in fuel economy is lacking. Data from other sources indicate that the benefits of lean operation at 19 to 1 A/F are less than 4% relative to a baseline system operating at 16 to 1 A/F, 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.

3.1.3.2 Ultrasonic Fuel System

The Ultrasonic Fuel System, developed by Dr. 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 flowrates 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. 3-12, 3-13). 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 A/F 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% enrichment of the mixture under acceleration conditions (Ref. 3-14).

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 A/F of 19. The inventors report that the fuel economy of this vehicle has been improved by 25% to 30%, 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. 3-14). No other fuel economy tests of this system have been made.

Emission test results in grams/mile for the same vehicle were reported in Ref. 3-12 as follows:

	HC	CO	NO_x
Without Device (Standard carburetor)	6.6	5.0	3.0 - 8.0
With Device	0.5	0.9	1.0 ± 30%

According to Ref. 3-14, 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 warm-up 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.

3.1.3.3 Cal-Tech Super Carburetor

The Cal-Tech "Super Carburetor" reported in Ref. 3-15 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 under 3.1.3.1.

3.1.3.4 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 under 3.1.3.5 and 3.1.3.6.

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 3-16 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.

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.

3.1.3.5 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. 3-17).

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

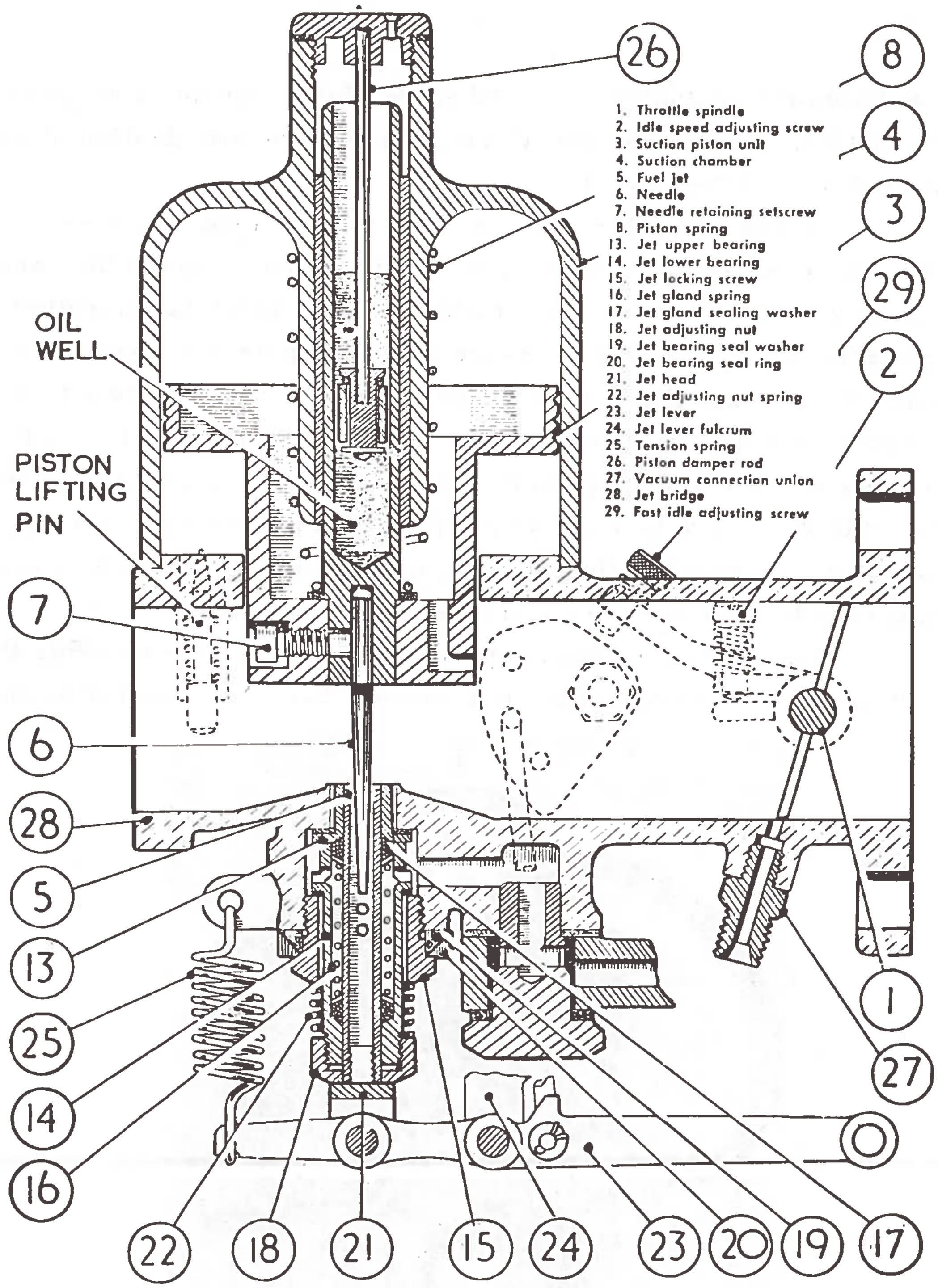


Figure 3-16. The Basic SU Carburetor

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 Figure 3-17 and Ref. 3-16).

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 that 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.

The secondary butterfly valve and its actuator controls the position of the fuel metering orifice in a manner basically similar to the Kendig

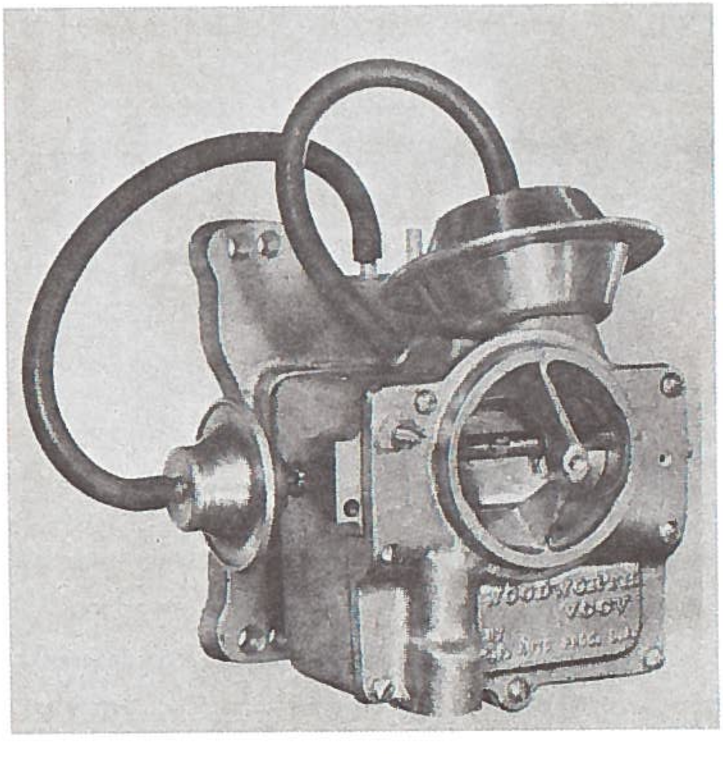


Figure 3-17. Woodworth Carburetor (Ref. 3-17)

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 to enrich 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 WOT, 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 to cut off the fuel flow.

Exhaust emission and fuel economy data (in grams/mile) obtained on a 1973 Chevrolet impala during a test conducted by Automotive Environmental Systems, Inc., were (Ref. 3-18):

	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 (Ref. 3-17), it was understood that the carburetor normally operates at a 15:1 A/F. 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 %) would be expected over operation at an A/F 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 fuel cutoff 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.

3.1.3.6 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. 3-19).

The carburetor is of a simple construction as shown in Figure 3-18. The primary components are a dual throttle plate, a spring-loaded dual "venturi" plate, a fuel spray bar, a fuel metering device, and a conventional fuel float chamber.

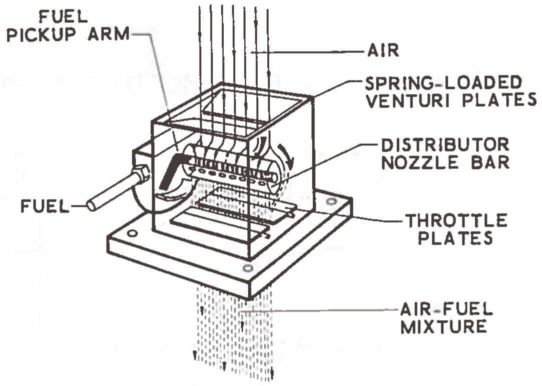


Figure 3-18. Kendig High Performance Carburetor

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. To change its effective flow area, this orifice, which is at the end of a pickup arm, traverses an arc within a ramp of variable depth. 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. 3-21), 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 the California Air Resources Board in February 1974, using a 1973 Pinto, are shown in Table 3-3 (Ref. 3-20). 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 the manufacturer's 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 reflect this improvement, however, are not available.

TABLE 3-3. 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

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 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 that provided by a conventional single butterfly.

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%) would be expected over operation at an A/F of 16(as in contemporary carburetors).

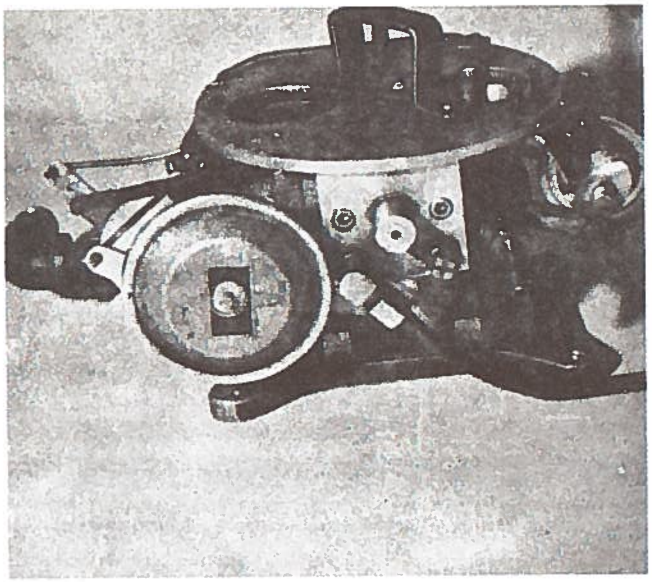
As in the Woodworth carburetor, the velocity in the mixing chamber is relatively low, and, therefore, potential for improved fuel atomization from the spray bar is compromised. The dual throttle blade configuration, however, could promote better liquid droplet distribution in the manifold and thus permit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

3.1.3.7 Arpaia Fuel Injection Carburetor

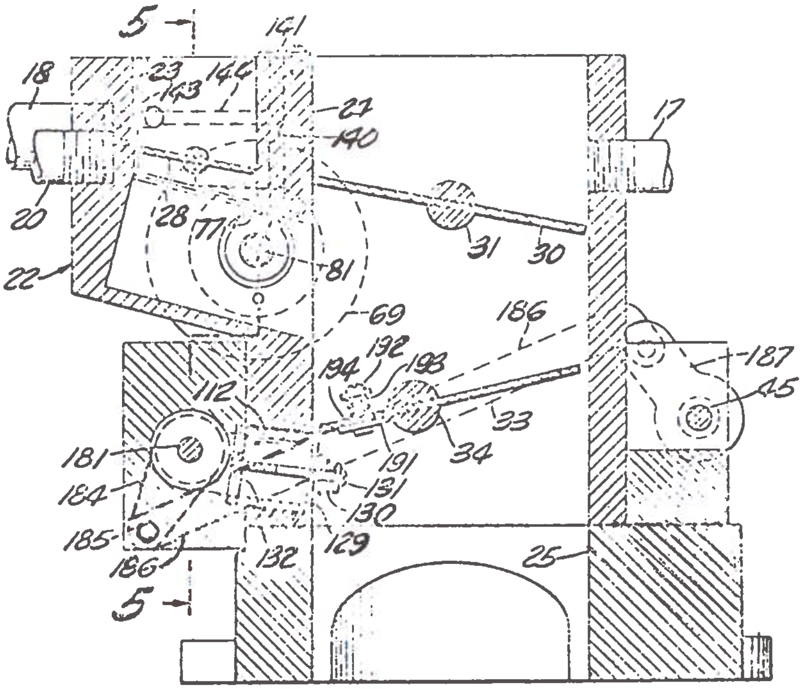
The patented Arpaia Fuel Injection Carburetor (Figure 3-19) is a development of Bruin Engineering, Inc., Lincoln, Nebraska. It contains a single, adjustable fuel valve to control fuel flow over the full range of engine operating conditions (Refs. 3-22 and 3-23).

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



(a) Photograph (Ref. 3-22)



(b) Representation from patent (Ref. 3-22)

Figure 3-19. The Arpaia Fuel Injection Carburetor 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 A/F 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.

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%), mountain and desert highway (45%), and freeway driving (45%), the test vehicle was reported to attain 17.8 miles per gallon (+18.7%) 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%) compared to 10.4 miles per gallon for the baseline vehicle.

Two hot-start, 7-mode emissions tests were conducted by Olson Laboratories on the same 400 CID Ford used in the fuel economy runs. Results of these tests (in grams/mile) with the Arpaia Carburetor were as follows (baseline tests were not conducted):

	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%), 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 are 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, in the effectiveness of the device on different makes and models of cars, and in 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 A/F 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 A/F during deceleration. This could result in a 10% to 15% 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.

3.1.3.8 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. 3-24 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 3-20 (Ref. 3-25) 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.

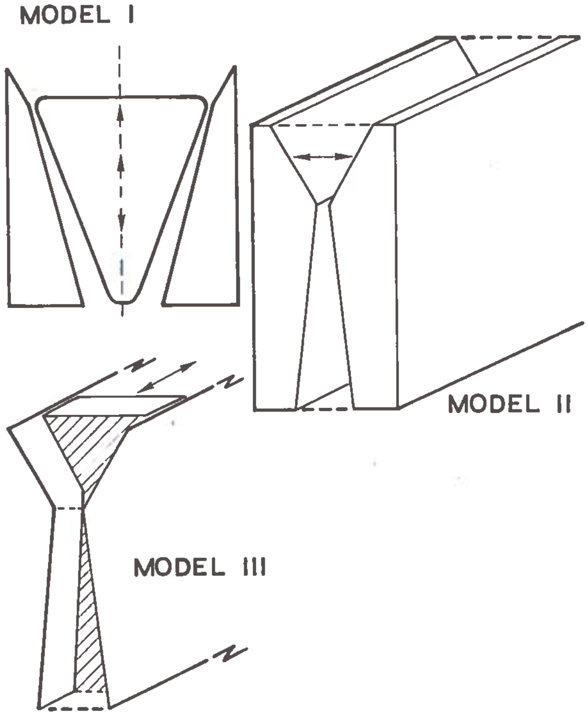


Figure 3-20. Dresserator Models (Ref. 3-28)

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 impaction 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 A/Fs of from 18 to 19:1. The sonic feature is 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. 3-24).

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 3-4. All of these 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

TABLE 3-4. DRESSERATOR SYSTEM 1972 FEDERAL CVS TEST RESULTS

	Emissions, g/mi			Fuel Economy (mi/gal)	Reference
	HC	CO	NO_x		
1971 Ford Galaxie, 351 CID					
1. Dresserator	0.3 - 0.5	4.5 - 7.5	1.2 - 1.7	10.5 - 11.0	3-24
2. Dresserator	0.32	4.68	1.58	10.8	3-26
3. Dresserator with Conventional Exhaust	0.8 - 1.0	6 - 7	1 - 1.3	11 - 13	3-27
4. Baseline	1.5 - 2.5	30 - 40	4.0 - 4.2	10.4 - 10.6	3-24
1973 Chevrolet Monte Carlo, 350 CID					
5. Dresserator	0.65 - 0.95	4.9 - 6.2	1.16-1.60	11.2 - 12.0	3-28
6. Baseline	1.71	24.0	2.42	11.6	3-28
7. Dresserator with Vac. Advance	1.07	5.84	2.00	13.0	3-28
1975 California Standards	0.9	9.0	2.0		

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 5% to 10% improvement in fuel economy under these conditions and believes this performance could be improved with the vacuum advance optimized for the Dresserator system. Entry No. 7 shows the results of one of several Dresserator tests with vacuum advance operative, indicating that some improvement by this technique may be possible with some slight loss in emission control.

In July 1973, the Dresserator System was reported to be in a research prototype stage of development (Ref. 3-24). Test fixtures of several versions of the Dresserator core have been made, utilizing both float bowl and compressive fuel feed systems (Ref. 3-28). The present status of the device with respect to manufacturing development is not known.

In summary, the fuel economy improvement potential for this system derives mainly from the advantages of improved atomization and mixing of the fuel charge which were earlier indicated to provide the potential for small increments of gain. The manufacturer is developing this device primarily as an emission-control system and has made relatively modest claims relating to fuel economy improvement. These appear to be within the range of possibility.

3.1.3.9 Fish Carburetor

The Fish Carburetor is a product of the Tyce Engineering Corporation of San Diego, California. This is a very simple carburetor which has been in existence for a number of years. Its primary claims are better engine response and an improvement in fuel economy (Ref. 3-29).

Except for the fuel metering device, all of the carburetor components are of conventional design (Ref. 3-30). They include an air throttle butterfly valve, a fuel float chamber, a manual choke, and a piston-type accelerator pump. The distinctive feature of this carburetor is the throttle-positioned fuel-metering device (Figure 3-21).

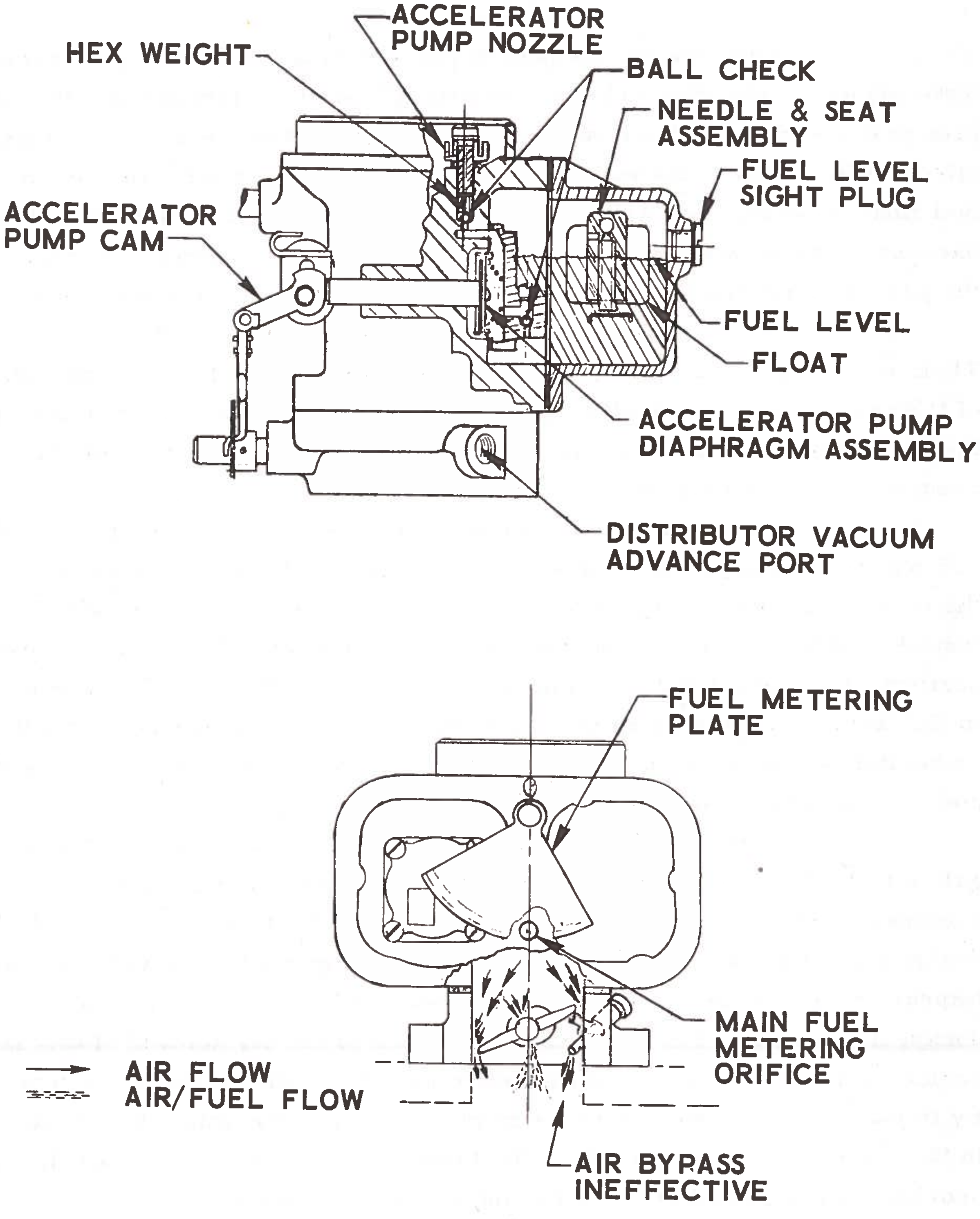


Figure 3-21. Fish Carburetor (Ref. 3-30)

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 resume the manufacture of this carburetor.

This carburetor, which has a throat diameter of approximately 1.5 inches, 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. 3-32). According to Edelbrock, it had a crisp response and there was no evidence of stumble or hesitation. At wide open throttle, however, there was approximately 30% 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. 3-31). 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% improvement at A/F = 19 to 20, compared to conventional operation at A/F = 16).

3.1.3.10 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. 3-33).

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 3-22). 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. 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.

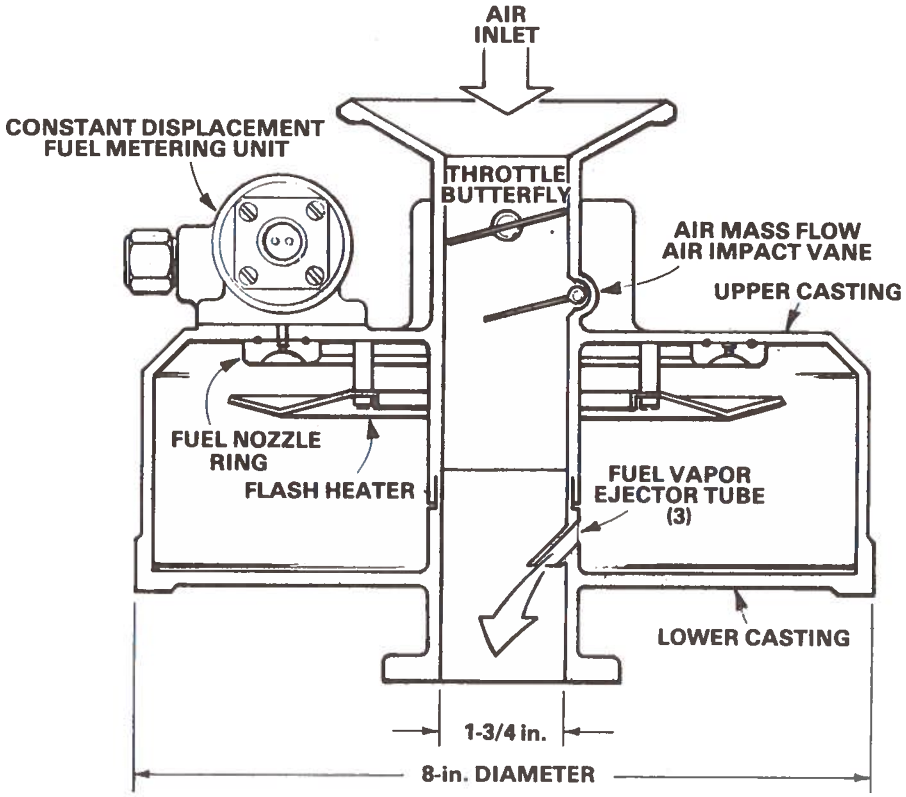


Figure 3-22. Gelb Carburetor (Ref. 3-33)

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 A/F 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 under 3.1.1.4.1, 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 are supplied by the manufacturer.

3.1.3.11 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 of gasoline. However, recent information indicates that Pogue's company never produced a carburetor (Ref. 3-34) and that Pogue feels the carburetor isn't applicable to the cars of today. Using patent drawings as a guide (Figure 3-23), 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. 3-35).

The distinguishing feature of the Pogue carburetor (Refs. 3-36, 3-37, and 3-38) 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 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

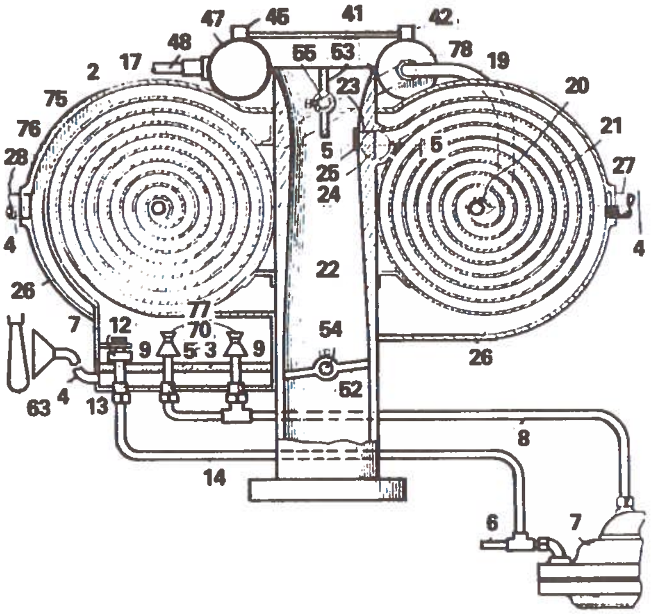


Figure 3-23. Representation of Pogue Carburetor (from patent) (Ref. 3-38)

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 Ref. 3-35.

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 under 3.1.1.4.1, 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% fuel vaporization during cruise conditions, complete vaporization might improve fuel consumption in the order of 15%. 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.

3.1.3.12 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 air/fuel 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. 3-39).

The main components of the fuel-metering device (Figure 3-24) 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 (Ref. 3-40 and 3-41). The carburetor does not have a float chamber, and fuel under pressure from a conventional engine-driven fuel

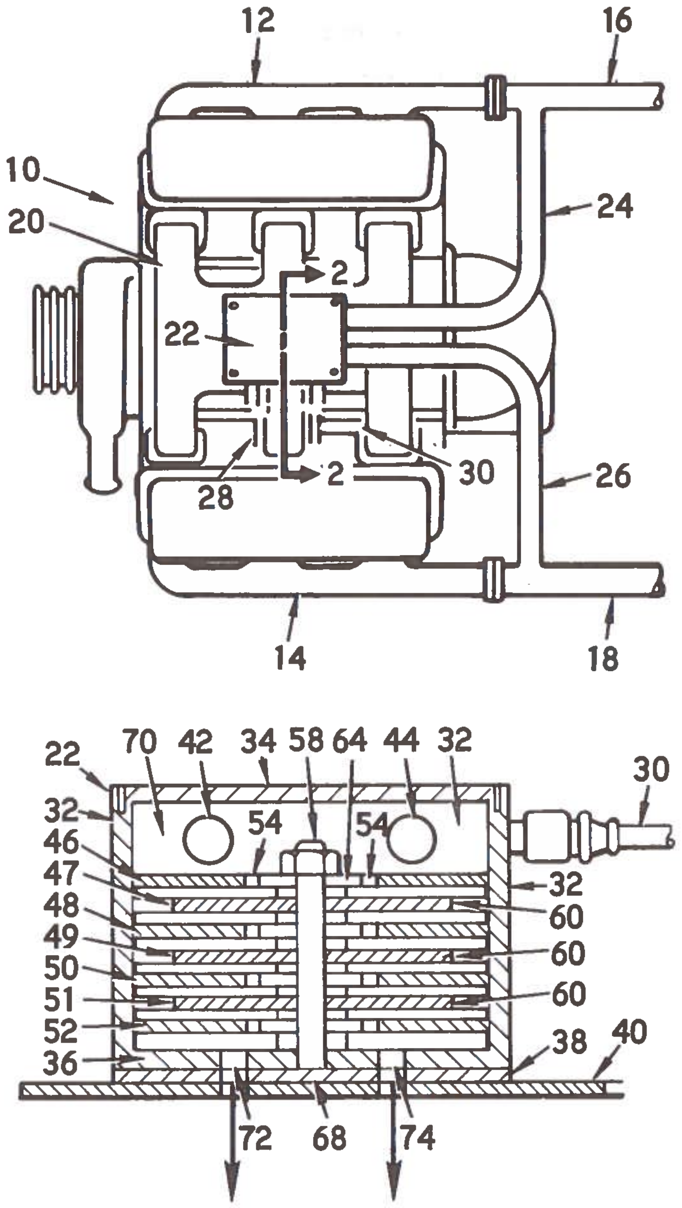


Figure 3-24. Representation of Fessenden Carburetor (from patent) (Ref. 3-40)

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 air/fuel mixture from the fuel-metering device, together with gas extracted from the exhaust pipe, is 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 3-25 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. 3-42), showed 100 parts per million (ppm) HC and 0.2% CO at 2500 rpm; 500 parts per million (ppm) HC and 0.6% CO at idle (500 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 high pressure loss through the baffles, however, is also inherent in the design and could result in a significant loss in power at WOT.

The fuel economy benefit potential by the fuel vaporization in the Fessenden carburetor is related to the degree of fuel vaporization 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 under 2.1.1.4.1.

3.1.3.13 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

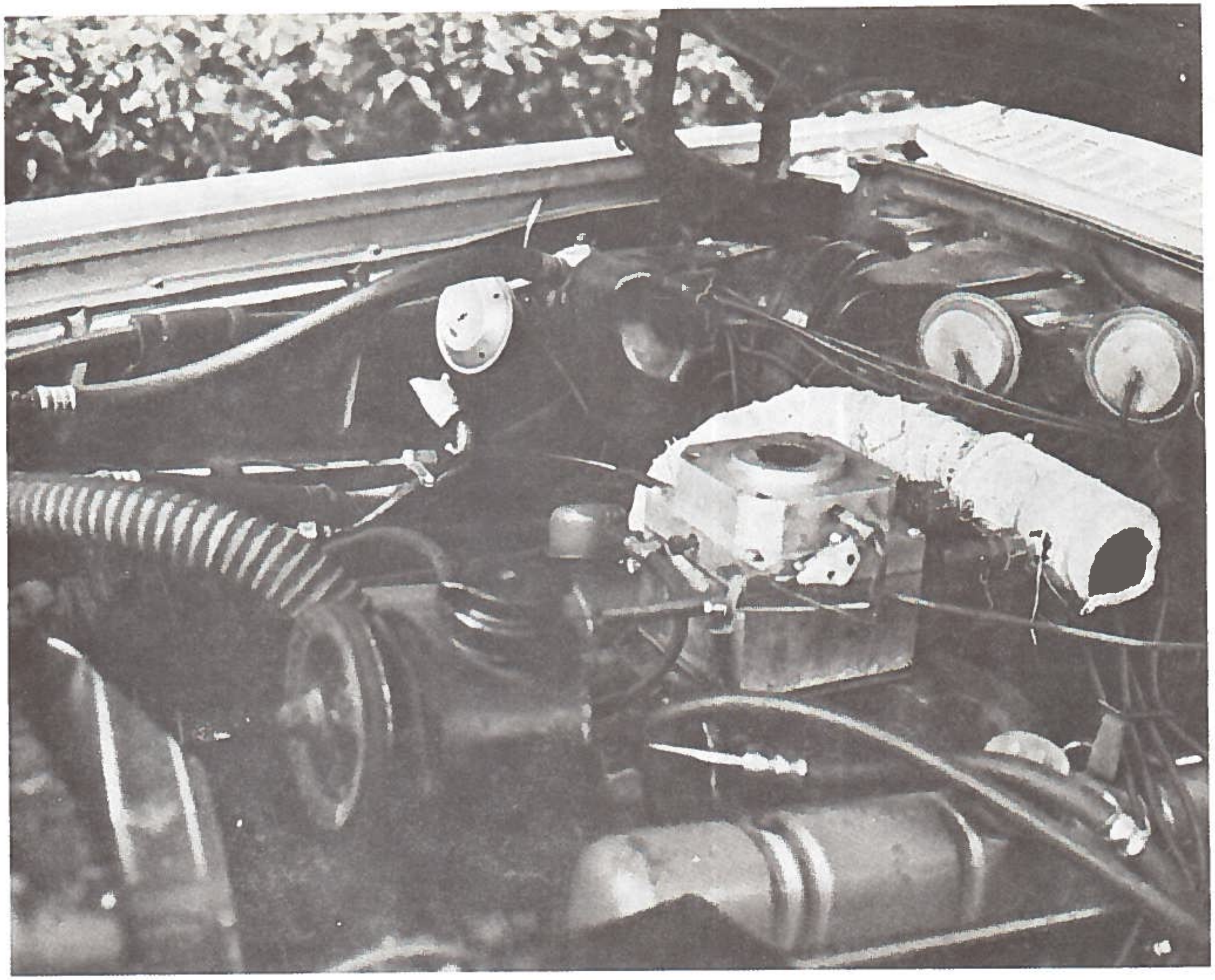


Figure 3-25. Fessenden Carburetor Installation

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 (Ref. 3-43 and 3-44).

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 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 3-26. The water injection feature shown in the drawing represents an early version of the device and has since been deleted from the system.

Approximately 5% to 18% of the exhaust gas is recirculated 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 A/F. 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, whereby, 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

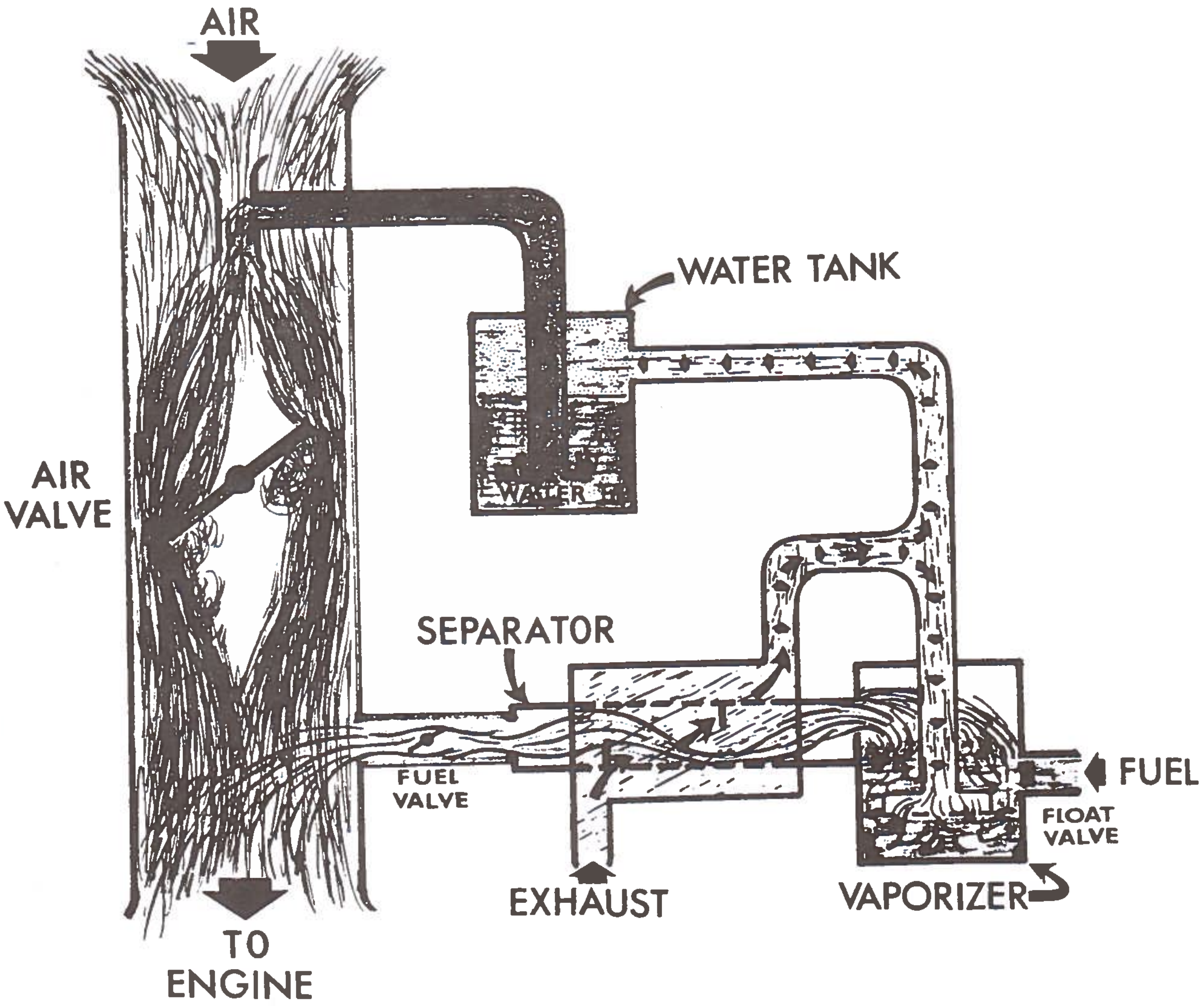


Figure 3-26. The Vaporator (Ref. 3-44)

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% 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 two to four 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 3% to 4% in most cases. This system may provide an additional increment of improvement by the proposed technique of shutting off the supply of fuel during rapid deceleration manuevers, but the effect on fuel economy over a representative driving cycle may be negligible.

3.1.3.14 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. 3-45).

In the design, schematically shown in Figure 3-27, 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.

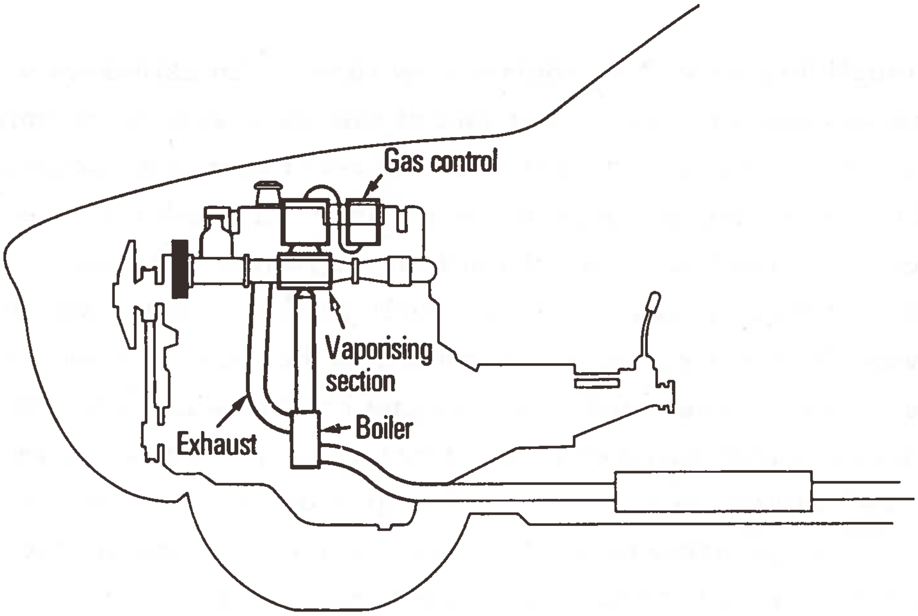


Figure 3-27a. Location of Vapipe

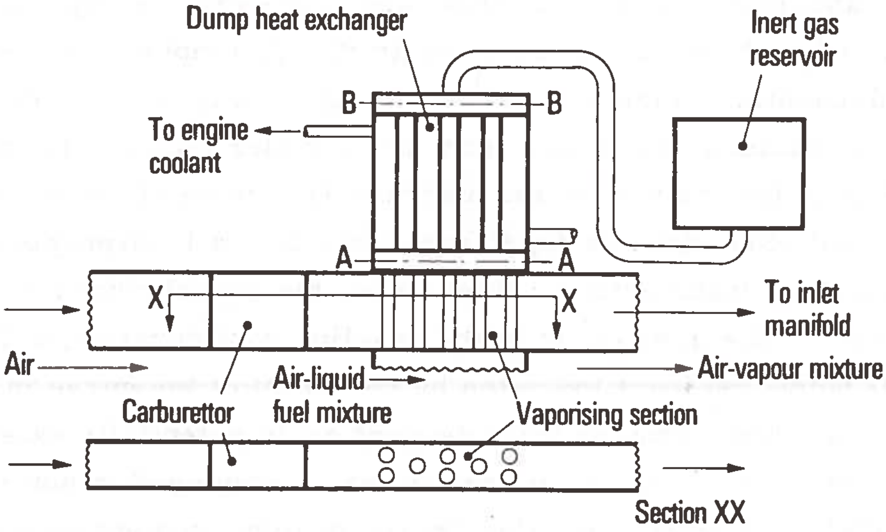


Figure 3-27b. Vaporizing Section and Gas Control System (Ref. 3-46)

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 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 3-5. 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% fuel economy improvement (as shown in Table 3-5 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 3-5 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.

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

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)

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.

3.1.3.15 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. 3-47), 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 Ref. 3-48 that the device was expected to sell for $20.00 to $25.00.

3.1.3.16 Ethyl Carburetor

The Ethyl Corporation has had a long term development program on emission-control systems utilizing lean thermal reactors (Ref. 3-49). Their system incorporates lean carburetion, exhaust gas recirculation, and thermal reactors. Although this sytem has not been developed for or proposed by Ethyl as a retrofit, it is reviewed in this section because of the carburetor developed by Ethyl for lean operation.

The effectiveness of the lean reactor system depends primarily on improved carburetion. A three-venturi carburetor (Figure 3-28) was developed to provide a high degree of atomization and mixing, along with close-tolerance metering of the air-fuel mixture. This carburetor utilizes high air velocities for mixing. Other design characteristics which also help include the geometry of the fuel nozzle, the use of perforations in the primary throttle plate through which the mixture passes under some conditions, and a mixing tube that extends into the intake manifold beneath the primary throttle.

High air velocities are produced by the use of a small primary venturi for light loads and two variable secondary venturis for higher power conditions. Thus, the high velocities present under all conditions not only provide mixing but also give strong metering signals at any engine condition. These signals, in turn, promote metering accuracy. In addition, the strong venturi signal permits elimination of the separate idle system and allows fuel for idling and light-load conditions to be provided through the main nozzle of the primary venturi, which also benefits mixing. Other refinements incorporated in the carburetor include a device for temperature-compensating the idle mixture ratio, an internal control to increase mixture flow during deceleration, and a temperature-modulated choke that closely relates both the degree and duration of choking to engine and under-hood temperatures. Use of these systems, even in conjunction with EGR, permits an idling A/F of about 17.2:1 and an operating A/F of 17-18:1 across the speed range. Enrichment to 12:1 A/F occurs at full power.

Several systems are used in the lean reactor to improve performance and emissions during the first few minutes after starting. Choking is carefully regulated and the idle air/fuel mixture is temperature compensated. In addition, the intake manifold is modified in the hot-spot section beneath the carburetor throats to transfer heat rapidly from the exhaust gas side of the manifold crossover to the intake side. This provides more rapid vaporization of fuel on the cold start. This modification consists of discs of finnned stainless steel that replace portions of the normal cast iron structure in the hot-spot area. A crossover heat control valve directs exhaust gas from one side of the

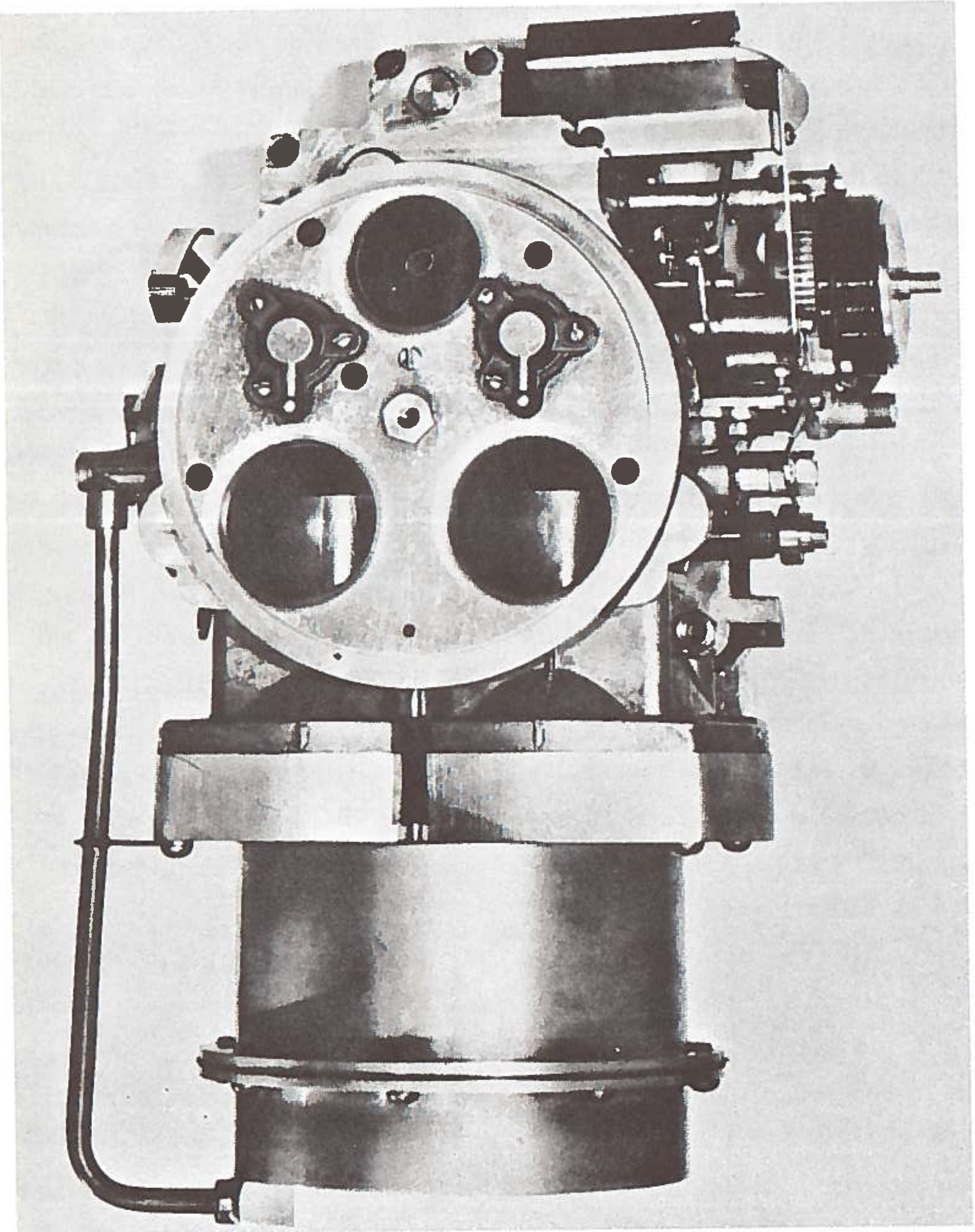


Figure 3-28. Experimental Three-Venturi Carburetor (Ref. 3-49)

engine through the crossover and out the other side during the cold-start period. After warmup, this valve opens, and the exhaust gas bypasses the hot-spot area. Carburetor air also is preheated rapidly by the use of a muff-type preheater installed at one reactor outlet. The conventional temperature control valve in the air cleaner opens after warmup to maintain carburetor air at the normal temperature.

A 1972 Fury III with a 360 CID engine and the Ethyl lean thermal reactor system was tested by EPA (Ref. 3-50). Three tests were conducted in accordance with the 1975 Federal Test Procedure (FTP) as described in the November 15, 1972, Federal Register. All test work was conducted at 4500 pounds inertia weight. The results from the tests are shown in Table 3-6. These results demonstrate that emission levels well below 1975 interim standards can be achieved with this system. For comparative purposes, an average 1972 FTP result was calculated using results from the first two bags of the reported 1975 test work. Comparison of this data with 1973 certification emissions levels and fuel economy is shown. This vehicle demonstrated significantly better emissions and fuel economy than a similar 1973 certification vehicle. General impression of vehicle driveability was good.

3.1.4 Comparison of Carburetor Devices

Table 3-7 summarizes the more significant characteristics and developmental status of the carburetors described in detail under 3.1.3.1 through 3.1.3.16. The fuel economy improvement claims noted in the table are those projected by the device manufacturer or promoter. Table 3-8 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 under 3.1.1.4.4, the air-fuel ratio is one important characteristic impacting fuel economy. However, increases in A/F to 20 would not be expected to increase steady-state cruise fuel economy more than approximately 4% to 5% over that obtainable with conventional carburetors operating at an A/F of 16.

TABLE 3-6. EMISSIONS AND FUEL ECONOMY
(1975 FTP VERSUS 1972 FTP)

1975 FTP

	HC gm/mi	CO gm/mi	NO_x gm/mi	CO_2 gm/mi	Fuel Consumption mpg
Test 1	0.78	5.93	1.42	756.49	11.23
Test 2	0.78	5.51	1.30	769.51	11.05
Test 3	0.87	5.77	1.42	746.80	11.96
Average	0.81	5.74	1.38	757.60	11.41
1975 Interim Standards	1.50	15.00	3.10	--	--
1976 Interim Standards	0.40	3.40	0.40	--	--

1972 FTP

	HC gm/mi	CO gm/mi	NO_x gm/mi	CO_2 gm/mi	Fuel Consumption mpg
Avg. 3 Tests	1.06	7.07	1.42	755.91	11.23
1973 Cert. Results	2.60	38.00	2.40	--	9.70

Another important characteristic is the degree of fuel and air mixing and distribution from cylinder to cylinder, as noted under 3.1.1.4.1 and 3.1.1.4.2. 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 warmup, idle, and light-load cruising conditions, fuel vaporization concepts (e.g., Arpaia, Gelb, Pogue, Vaporator, Fressenden, Vapipe) and fuel atomization concepts (e.g., Electrosonic, Ultrasonic, Kendig, Arpaia, Dresserator, Ethyl) could have more beneficial effects.

TABLE 3-7. CARBURETOR DEVICES SUMMARY (CHARACTERISTICS AND DEVELOPMENT STATUS)

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	Development prototype	$65-70	.75
Woodworth Carburetor	Air-valve carburetor	Carburetor only	Improvement (a)	Improvement (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 Improvement (a)	Development prototype	$110	1
Dresserator System	Sonic variable - Venturi system	Atomizer, modified intake & exhaust manifolds	5-10% (c)	1975 Cal. Standards (c)	Not Specified	Development prototype	--	--

see next sheet for footnotes

TABLE 3-7. CARBURETOR DEVICES SUMMARY (CHARACTERISTICS AND DEVELOPMENT STATUS) (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	--
Ethyl Carburetor	Three-venturi carburetor	Carburetor only	No Specific Claims	Below 1975 Interim Standards (c) (f)	No Specific Claims	Development prototype	--	--

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
(f) With complete Ethyl Lean Thermal Reactor System

TABLE 3-8. 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 3-72 for footnotes

TABLE 3-8. COMPARISON OF CHARACTERISTICS (AS RELATED TO FUEL ECONOMY IMPROVEMENT POTENTIAL) (Continued)

Characteristic / Carburetor	Air-Fuel Ratio and Effects[1]	Mixing and Distribution Effects: Atomization[2]	Mixing and Distribution Effects: Vaporization[3]	Mixing and Distribution Effects: Superheat[4]	Warmup Effects[5]	Choking Effects[6]	Deceleration Effects[7]	Hardware Availability for Testing[8]
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 3-72 for footnotes

TABLE 3-8. 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 3-72 for footnotes

TABLE 3-8. 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	
Ethyl Carburetor	A/F = 17-18. Should enable small fuel economy improvement (1-2%) compared to A/F of 16.	Should improve fuel atomization due to high air flow velocity in primary flow passage	N.A.	N.A.	N.A.	N.A.	N.A.	Should be available (not being developed for retrofit)

NOTES:

[1] Refers to the basic effect of air-fuel ratio on fuel economy at the warmed-up, steady-state cruise condition. Discussed under 3.1.1.4.4 and illustrated in Figure 3-14.

[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 under 3.1.1.4.1 and illustrated in Figure 3-6.

[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 3-6).

[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.

Similarly, those concepts which tend to promote faster warmup (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 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 noted in paragraphs 3.1.3.1 through 3.1.3.16, such comparative test data are 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 A/F of 16) more than ~10%.

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 the carburetor concepts which permit lean operation (A/F = 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 A/Fs in the 18 to 20 range raises the possibility of realizing not only the potential fuel economy improvements of lean burning (4% to 5%) 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 3-4, line 7), 12% improvement in fuel economy was obtained with slightly lower NO_x levels than by the baseline 1973 Chevrolet with EGR and no vacuum advance (Table 3-4, 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.

There are, undoubtedly, many other specific approaches to carburetor improvement being conceived, developed, and promoted in the United States today, aside from those discussed previously. 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 (A/F >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 cbtaining 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. 3-51) and the Motor Vehicle Manufacturers Association (Ref. 3-52); 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.

3.1.5 Carburetor 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, warmup, 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 6%) 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% relative to precontrolled 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%, relative to precontrolled vehicles, and up to 25% to 30% 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 3-9, together with a summarization of their operating principles 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

TABLE 3-9. CARBURETOR DEVICES SUMMARY (RELATIVE SUITABILITY)

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 3-9. CARBURETOR DEVICES SUMMARY (RELATIVE SUITABILITY)(Continued)

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 3-9. CARBURETOR DEVICES SUMMARY (RELATIVE SUITABILITY) (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 3-9. CARBURETOR DEVICES SUMMARY (RELATIVE SUITABILITY) (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.
Ethyl Carburetor	Three-venturi carburetor	Carburetor only	Development prototype	Acceptable for further evaluation	Potential for lean operation. Merits further evaluation, particularly for comparison with cars incorporating EGR for NO_x control. Improved fuel atomization should also be beneficial. Test unit should be available.

[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.

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 3-9 provides an indication of the relative current interest in these carburetor concepts for later analysis and/or test evaluations. The levels of relative ranking are:

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 3-9 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.

The available data for any of the concepts are insufficient 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 these types of data are made available, specific fuel economy claims should be viewed with caution.

3.2 CARBURETOR-RELATED DEVICES

The carburetor-related devices considered in this report consist of hollow needle screws to be used as a replacement for the standard idle mixture adjusting screws of a carburetor. This creates a leaner air-fuel ratio during idle and deceleration (high manifold vacuum) and results primarily in a reduction in CO, and, to a lesser extent, HC. Improved fuel economy is also claimed by the manufacturers, although this has not been substantiated by the limited test data available.

3.2.1 Econo-Needle

The Econo-Needle is an exhaust emission control device developed by Mr. H. P. Rock, Salt Lake City, Utah. The Econo-Needles replace the stock idle mixture screws on the carburetor. The Econo-Needle replacement screws are available in six sizes, covering a significant proportion of the vehicles currently being operated in the United States.

The Econo-Needles are hollow, allowing air to bleed through with the intended effect of leaning the air-fuel ratio. Installation instructions supplied with the device call for the Econo-Needles to be screwed in until they are seated and then backed off one-half turn. The use of a garage-type combustion analyzer, while not specified in the instructions, would enable more precise setting of the lean idle mixture.

Emissions (and fuel economy) tests of the Econo-Needles were made by the Environmental Protection Agency (Ref. 3-53). Three test vehicles were used: a 1962 Chevrolet Biscayne (283 CID), a 1963 Ford Galaxie (289 CID), and a 1970 Plymouth Valiant (225 CID). All three vehicles were equipped with automatic transmissions.

The Valiant and the Galaxie were subjected to three test configurations: baseline, recommended normal Econo-Needle setting, and minimum idle CO setting. After baseline testing, Econo-Needles were installed according to installation instructions, and the cars were again tested. Subsequently, the idle CO was set at a minimum level with the Econo-Needles, and the two vehicles were retested. The Biscayne was tested in the baseline and lean-set Econo-Needle configurations only.

All testing was performed in accordance with the 1972 CVS Federal Test Procedure. Fuel economy was calculated from the emissions data.

The emission test results (percent reduction from baseline) for the three vehicles equipped with the Econo-Needles are summarized as follows:

	1962 Chevrolet		1963 Ford		1970 Plymouth	
	Normal Set	Lean Idle	Normal Set	Lean Idle	Normal Set	Lean Idle
HC	---	+ 7	+ 7	-2	- 5	0
CO	---	+30	+10	+5	-19	+33
CO_2	---	- 9	- 2	0	+ 3	- 1
NO_x	---	-14	-18	-5	+ 4	- 2

Fuel economy calculations for the three vehicles indicated the following results (percent change from baseline):

1962 Chevrolet		1963 Ford		1970 Plymouth	
Normal Set	Lean Idle	Normal Set	Lean Idle	Normal Set	Lean Idle
---	-4	+1	+1	0	+4

The HC and CO levels were reduced in the vehicles tested with careful combustion analyzer setting of the Econo-Needles, while the

NO_x level tended to increase. However, similar reductions of HC and CO might also be expected from resetting the standard idle mixture screws.

The fuel economy results from these tests of the Econo-Needles are mixed and do not permit any firm conclusions to be drawn regarding the capability of this device to measurably improve vehicle fuel economy. Until more conclusive data become available, they should not be considered for further evaluation in this program.

3.2.2 Wyman Valves

The Wyman valves, developed by Mr. Curt Wyman of Germany and marketed by Aquablast, Inc., Ontario, Canada, replace the standard idle mixture adjusting screws of the carburetor in a four-cycle internal combustion engine. Each needle has a hole drilled through the length of the adjusting screw so that air flows through the needle during idle and deceleration (high manifold vacuum). When the manifold vacuum drops below 15 in. Hg during acceleration and high speed, a coil spring inside the Wyman valve pushes a ball against a seat to close off the air flow through the valve. A diagram of the Wyman valve is shown in Figure 3-29. A significant reduction in CO is claimed by the manufacturer for this device.

Tests of the Wyman valve were conducted by the EPA (Ref. 3-54) on two vehicles, a 1963 Ford (289 CID) and a 1970 Chevrolet (350 CID). All tests were performed according to the 1975 Federal Test Procedure. Both vehicles were set to the manufacturer's recommended idle rpm and

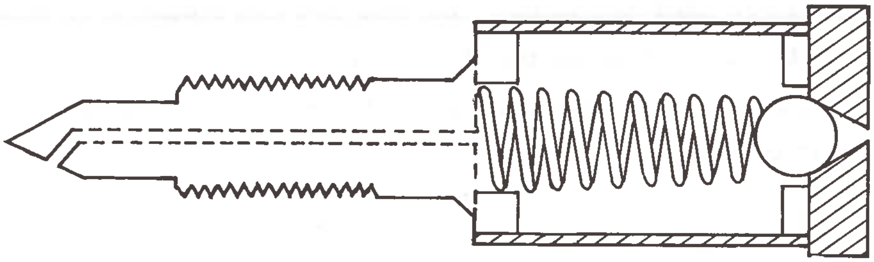


Figure 3-29. Wyman Valve (Ref. 3-54)

timing prior to testing. Two tests of each vehicle were conducted in both the baseline configuration and with the Wyman needles installed.

The test results showed a reduction in both HC and CO with the Wyman valves installed, while NO_x emissions decreased slightly in one vehicle and increased in the other. Fuel economy was stated to be not significantly affected (Ref. 3-54). Test results (percent decrease from baseline) are summarized as follows:

1970 Chevrolet	HC	13
	CO	19
	NO_x	4
	mpg	0
1963 Ford	HC	6
	CO	29
	NO_x	-17 (increase)
	mpg	-3 (increase)

3.2.3 Summary

The carburetor-related devices considered are hollow replacement screws for the stock idle adjusting screws on a carburetor. The hollow screws permit some outside air to bleed into the air/fuel mixture, thereby providing a somewhat leaner air-fuel ratio, particularly at idle and deceleration. Limited test data on these devices are contradictory, so that no firm, positive conclusions can be drawn regarding the ability of these devices to measurably improve fuel economy. Unless the developers of these devices can furnish additional performance data which show consistently improved performance, it is recommended that these devices not be included in the test phase of the current program.

3.3 ATOMIZERS

3.3.1 Acoustic Atomizers

Fuel atomization by high frequency (ultrasonic) vibrations is a feature of several devices designed to improve fuel economy or emissions. These include the Electrosonic Fuel Induction System and the Post Carburetor Atomizer device marketed by Autotronic Controls Corporation; the Ultrasonic Fuel System being developed by Dr. A. K. Thatcher of Merritt Island, Florida, and E. McCarter of Orlando, Florida; and the Echlin NO_x control retrofit device produced by the Echlin Manufacturing Company. Of these, only the Post Carburetor Atomizer (PCA) is being marketed as a separate unit for retrofit as a fuel economy device. In the other systems, the ultrasonic device is a component of a multi-element fuel delivery or emission-control package. These systems are discussed elsewhere in this report under carburetor concepts.

The Post Carburetor Atomizer is produced by the Autotronic Controls Corporation of El Paso, Texas. In principle, it is the same device as the atomizer unit in the Autotronic Electrosonic Fuel Induction System, but it is designed and marketed to operate as a separate unit. The device consists of a "wafer" containing a piezoelectric crystal which drives a resonant disc vibrating in a flexural mode. This disc, when driven at ultrasonic frequency, acts to break up fuel droplets impinging upon it as the air-fuel charge passes through the wafer from the carburetor to the manifold. The impinged fuel droplets are reduced to a fine spray and mixed with the surrounding air flow. Figure 3-30 is a sketch of the wafer and its component parts for an updraft carburetor. In Figure 3-31, the flow path for an atomizer fitted to a two-barrel carburetor is shown.

The only performance data available on the PCA were those obtained in a telephone call to Autotronic Controls Corporation representative Jack C. Priegel (Ref. 3-55). According to this source, the PCA fuel economy gain for suburban driving conditions could be as high as 27%. At 55 mph cruise, the gain is claimed to be about 10%.

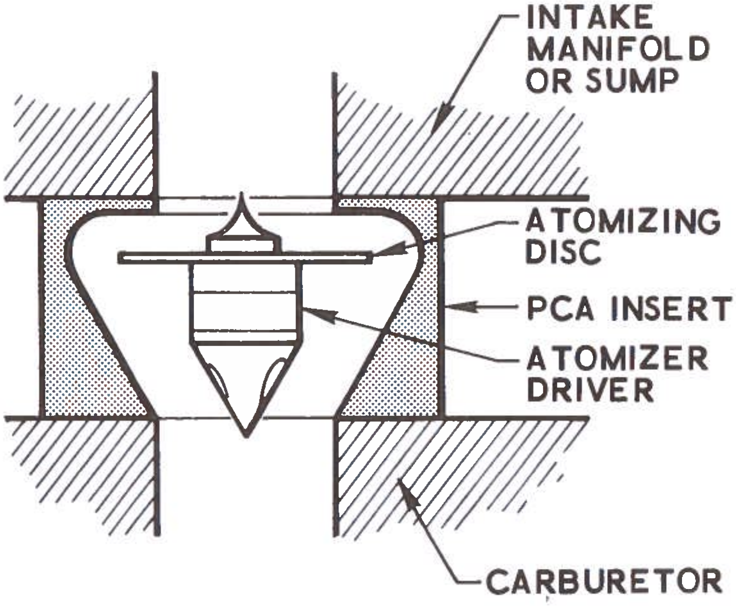


Figure 3-30. Post-Carburetor Atomizer

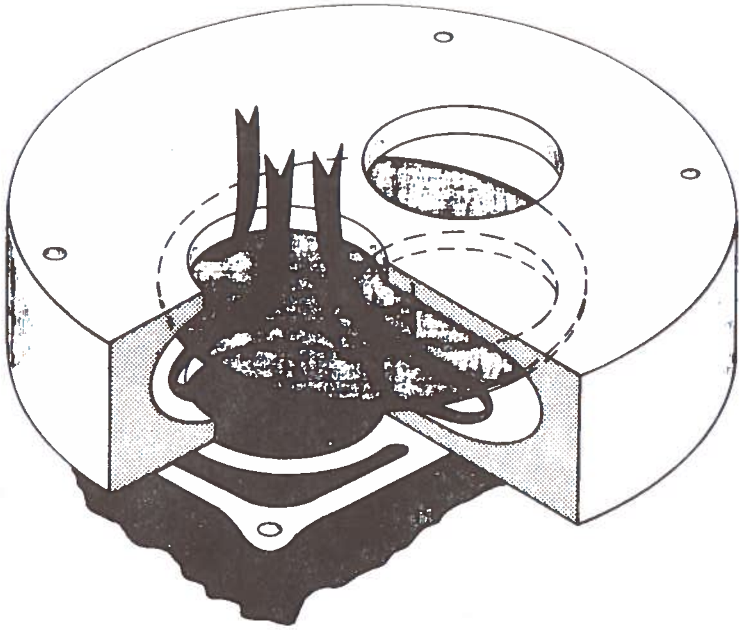


Figure 3-31. Air Flow Around PCA (Two-Barrel Carburetor)

The manufacturer states that the design objective for the PCA was to improve fuel consumption in a suburban driving mode or a "wife-to-store" cycle. This is primarily a cold-engine cycle, since the average trip length is 10 miles or less. Typically, fuel economy is poor for such driving due to the fact that engine does not reach a high enough temperature to properly vaporize the fuel. When this happens, the carburetor must be choked to provide a rich enough mixture to all cylinders to ensure smooth running. In some cylinders, the mixture may be too rich with a consequent waste of fuel and an increase in emissions. The manufacturer claims that ultrasonic atomization can be of substantial benefit in this mode, providing the atomized fuel is well mixed with the air stream. If this is the case, a properly distributed fuel charge can be delivered to all cylinders with a reduced amount of fuel. Thus, with the device installed, choking requirements are relieved, and the carburetor can be adjusted for leaner operation.

At present, Autotronic Controls considers the PCA to be experimental; it is not available for general distribution. A large share of the development cost for the PCA (as well as the Electrosonic Fuel Induction System) has been borne by the Ford Motor Co. Most of the PCA devices that have been built have been furnished to Ford for test and evaluation. The results of these tests are considered to be the property of Ford and are, therefore, not available for release.

The known information pertaining to the evaluation of the PCA device is summarized in Table 3-10. With regard to applicability, there are no known restrictions on this device. Installation time and cost should be relatively low, although removal and reinstallation of the carburetor is involved. The cost of the device is estimated at $55.00.

Lack of performance data prevents a complete assessment of the potential of this device. As a class, ultrasonic atomizers appear to have some promise for fuel economy improvement and emission reduction, primarily as a consequent of providing improved vaporization of the fuel under cold or warmup engine conditions. It should be noted that in large measure,

TABLE 3-10. EVALUATION SUMMARY FOR POST-CARBURETOR ATOMIZER

Degree of Fuel Economy Improvement	Developer claims 10%-27%, depending on driving cycle
Kit Content	"Wafer" containing piezoelectric crystal and vibrating disc exciter which converts 12 V dc to high frequency input; cost - $55
Mass Producibility	No problems anticipated
Availability	Experimental device not available to public
Applicable Models	No known limitations
Installation Requirements	Carburetor removal and remount, adjustment for lean operation
Installation Time and Cost	1 hr - $15
Maintenance Requirements	Check exciter output periodically
Effect on HC, CO, and NO_x Emissions	No data provided
Effect on Vehicle Power, Driveability	Unknown
Types of Data Available	Manufacturer brochures
Reliability of Data Base	No performance data provided

warmup performance depends on the mixing and distribution of the air/fuel charge subsequent to atomization, so that proper induction system design is additionally required to exploit the value of fine atomization under these conditions. Relative to a fully warmed engine, the improvement in fuel economy and emissions with this device may be extremely small; perhaps 2% or 3% for fuel economy. Nevertheless, the value of the warmup improvement cannot be discounted, since trip statistics indicate that a preponderance of individual car trips are completed with the engine still in the transient warmup phase.

Without certified laboratory results on emissions and fuel economy, it is difficult to recommend this device for further examination. However, since the PCA is a component of the Electrosonic Fuel Induction System which is recommended for test, the testing of this device as a single component might be accomplished in concert with tests on the overall system with very little additional difficulty and expense.

3.3.2 Mechanical Atomizers

Included among the devices classified here as mechanical atomizers are the Hydro-Catalyst System; the Spartan II Atomizer; an apparatus referred to as "The Vaporizer" by its inventor, R. G. Kolb; and an air/fuel mixture deflection device by F. O. Wieseman. The first three of these systems are screen configurations; the fourth is a deflector plate. These devices are illustrated in Figures 3-32 through 3-37 (Refs. 3-57 and 3-58).

These systems do not operate as atomizers in the conventional sense; that is, they do not convert the kinetic energy of the stream into shearing forces to reduce droplet size. Rather, the screen systems function to provide a large surface area for fluid impingement and collection to enhance vaporization, while the deflector device imparts a swirl to the flow, presumably to improve vaporization and atomization by turbulence and mixing. As far as the latter processes are concerned, the Wieseman deflector comes closest in principle to being a conventional atomizer; however, the usual swirl-type atomizer for flow rates of this magnitude has much smaller flow passages and operates at a much higher pressure drop.

As shown in Figure 3-32, the Hydro-Catalyst consists of a plate fitted with conical screen cups, one cup for each carburetor barrel. The plate assembly is shaped for installation as an adapter between the carburetor and intake manifold. Each cup consists of two wire mesh screens separated by a gasket, as illustrated in Figure 3-33. According to the patent description, the wire screens are treated to present catalytic surfaces to the carbureted air/fuel mixture. Best results are said to be obtained with the upstream wire mesh coated with cadmium and the downstream mesh coated

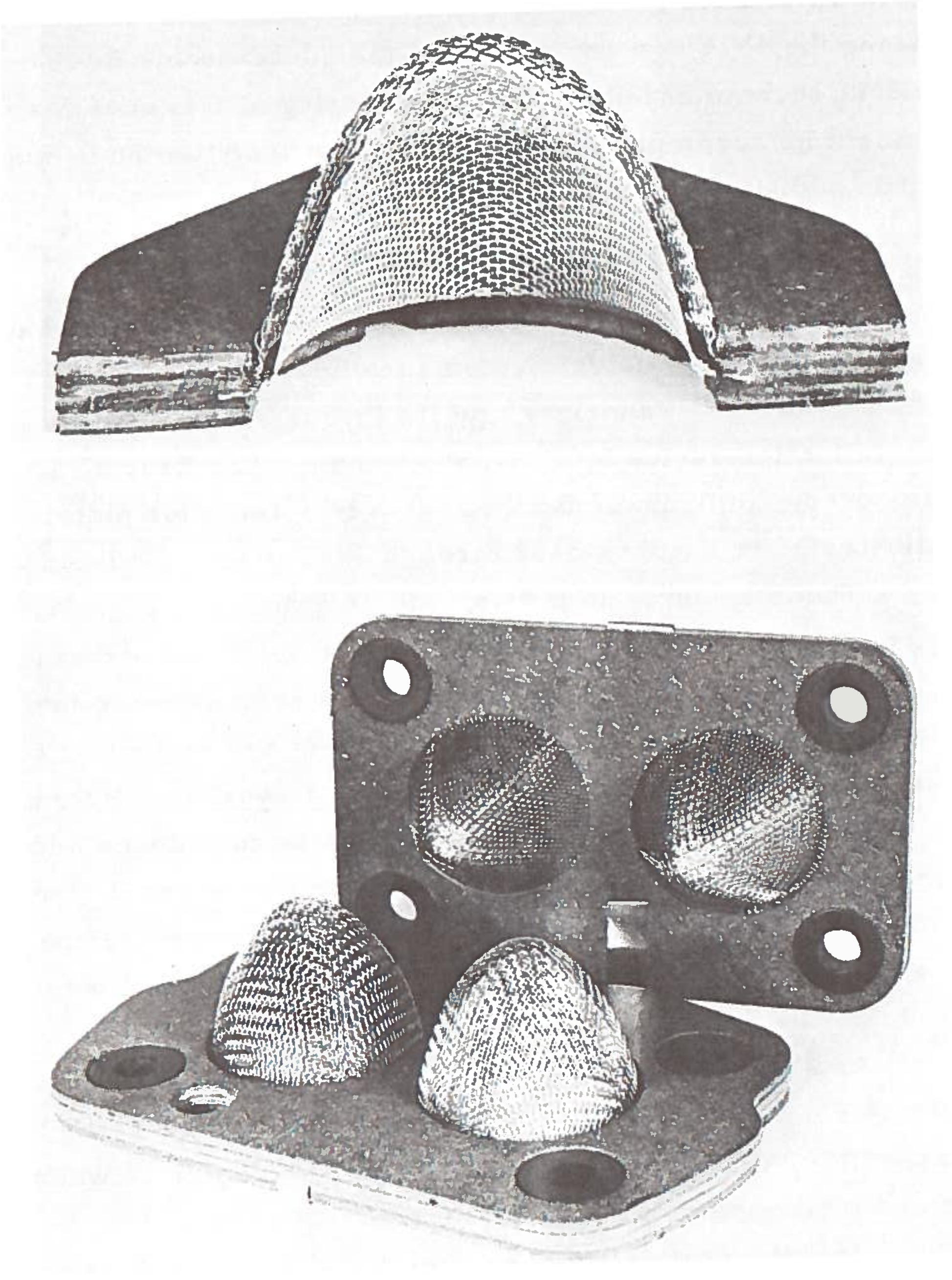


Figure 3-32. Hydro-Catalyst Atomizer, Two-Barrel Carburetor Application

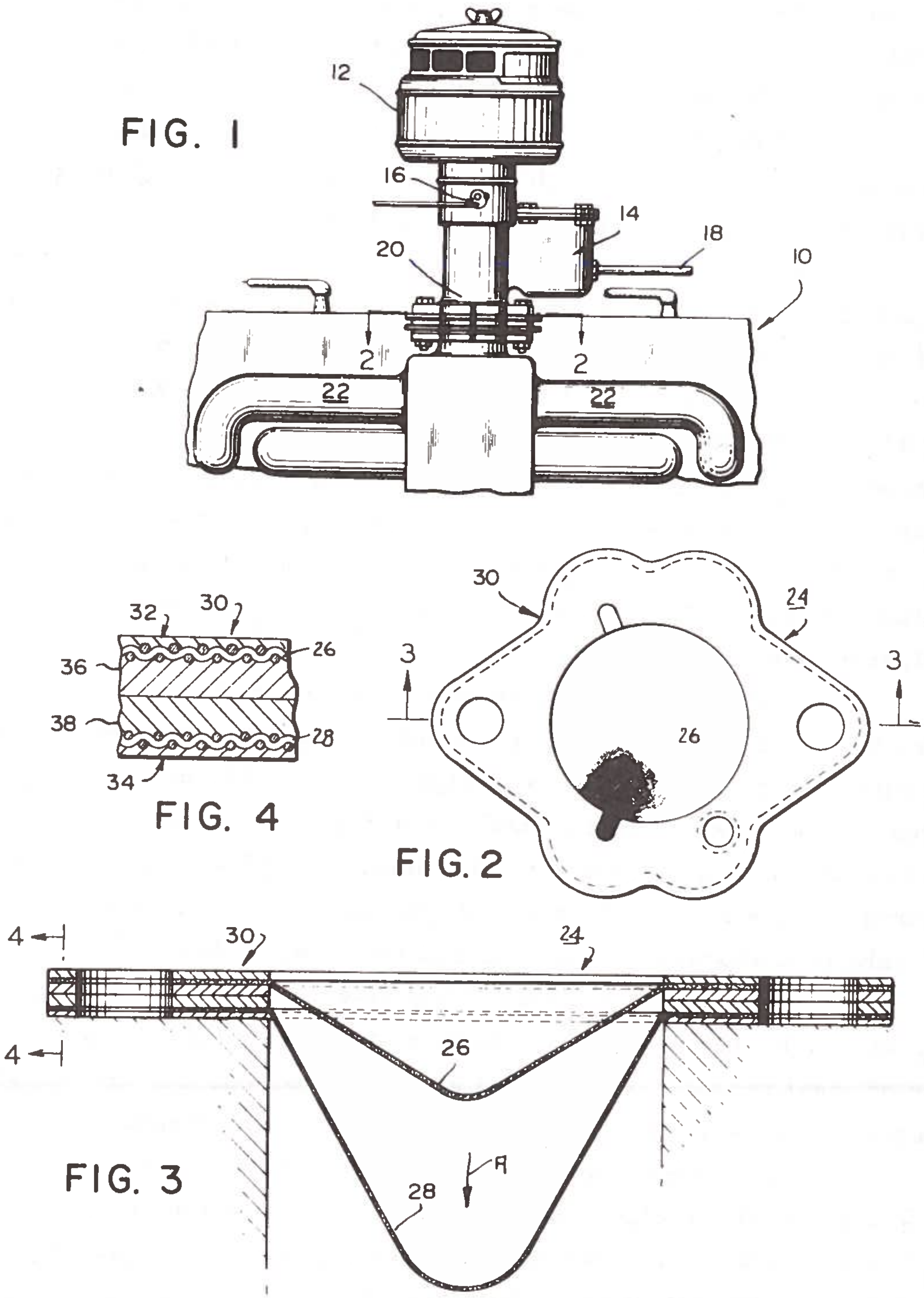


Figure 3-33. Hydro-Catalyst Installation (Representation from Patent)

with nickel. The use of dissimilar metals separated by the dielectric gasket material is said to provide the properties of a battery which assists in the operation of the device as described below.

The presence of the screen is claimed to induce a pre-combustion catalytic effect which causes the combustion process to proceed in a preferred, more efficient chemical path, suppressing the tendency for detonation to occur. The inventor cites several references which are stated to support the notion that the combustion process can be altered by first passing the air/fuel mixture over a catalyst external to the combustion chamber. On this basis, the Hydro-Catalyst is claimed to effectively increase the octane rating of the gasoline burned. In addition, fuel economy benefits are said to be derived from the electrostatic action of the dissimilar metals used in the wire mesh. This is supposed to act as a battery and charge the droplets of fuel as they pass through the screen. The droplets are then attracted to the oppositely charged manifold surfaces where the heat of the wall enhances vaporization (Ref. 3-59).

The Spartan II, developed by Compression Dynamics Inc., Skokie, Ill., is a wire-screen-type atomizer made from stainless steel mesh with a brass grommet insert (Figure 3-34). The device is located between the carburetor and the intake manifold. At low speeds, the wire mesh is claimed to break the fuel into smaller droplets, and, at high speeds, the grommet acts to pass the high volume flow and to create a vortex action which enhances atomization and vaporization (Ref. 3-58).

The Kolb Vaporizer, illustrated in Figure 3-35, consists of a conical nozzle insert into which is fitted a porous conical cup made of three layers of steel screen. The conical nozzle and porous cup are installed between the carburetor and intake manifold as shown in Figure 3-36.

The Wieseman deflection device, shown in Figure 3-37, consists of a plate with varied shaped deflectors which extend into the manifold. The plate is coated with a nonwettable fluorochemical coating. According to the developer, the deflection of the air/fuel mixture by the vanes aids in vaporizing the fuel, while the nonwettable surface coating avoids filming of the mixture on the deflection prongs (Ref. 3-57).

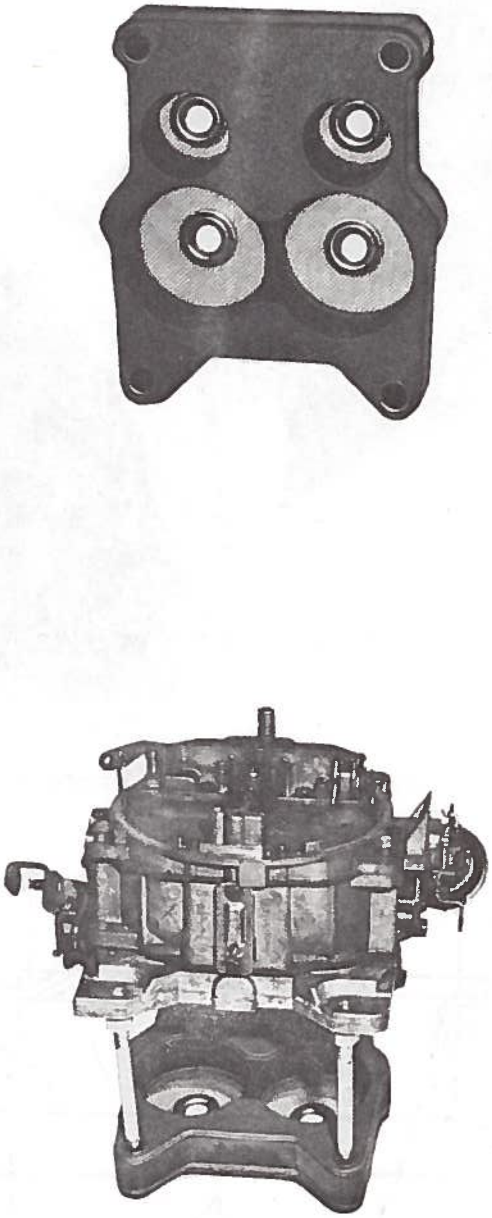


Figure 3-34. Spartan II Atomizer

Figure 3-35. R. G. Kolb "Vaporizer"

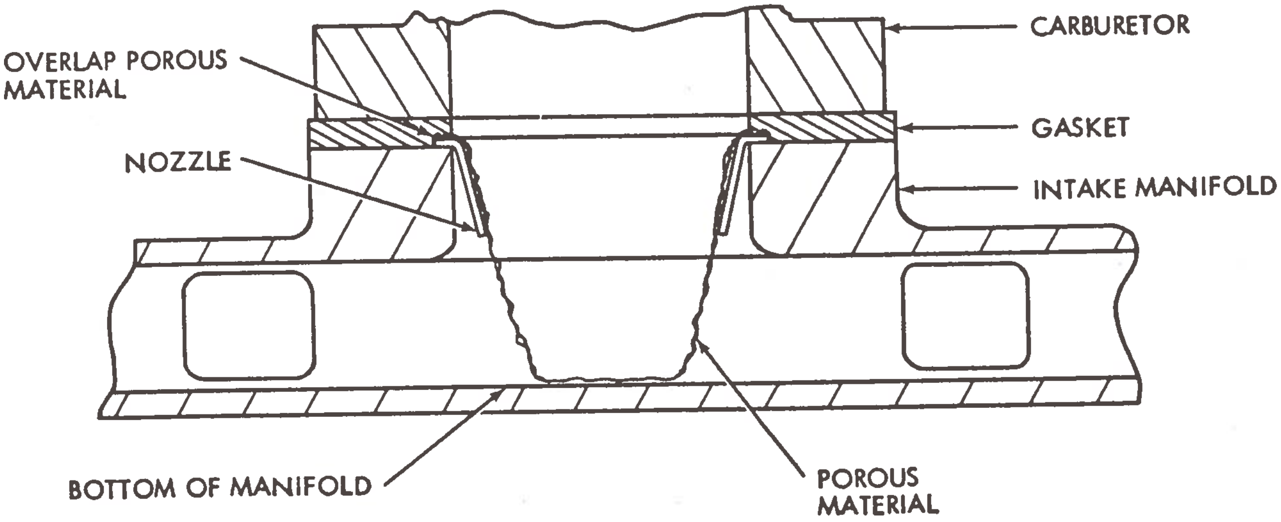


Figure 3-36. R. G. Kolb "Vaporizer" Installation

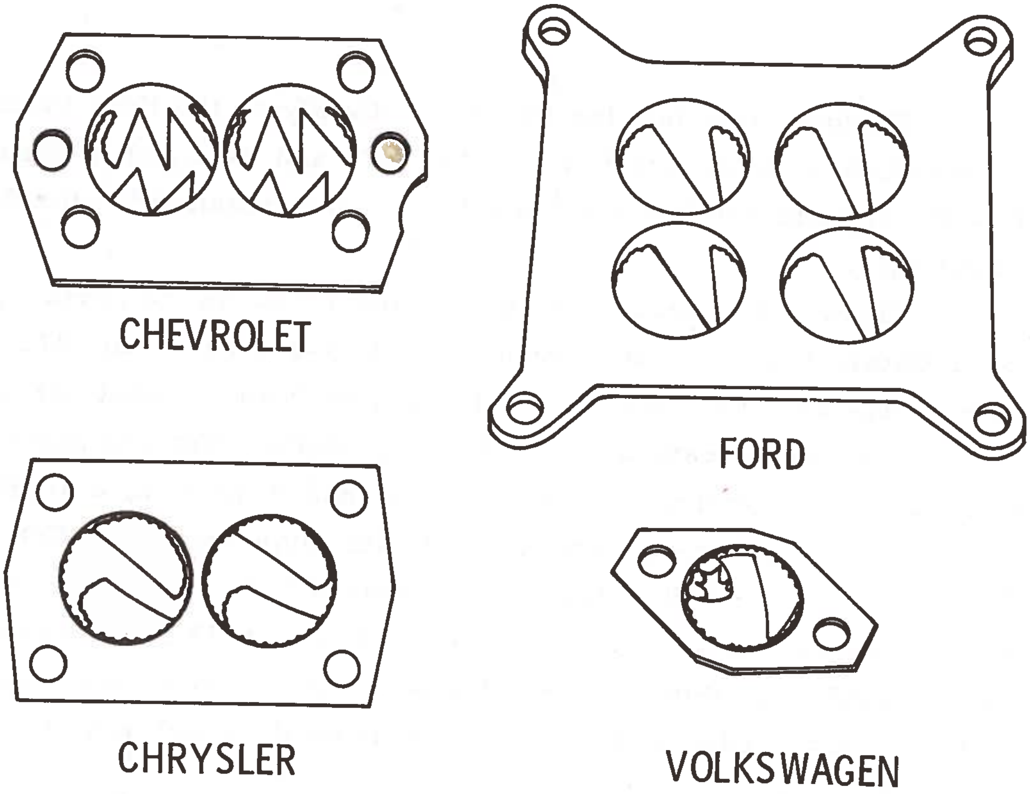


Figure 3-37a. Air/Fuel Mixture Deflection Device by F. O. Wieseman

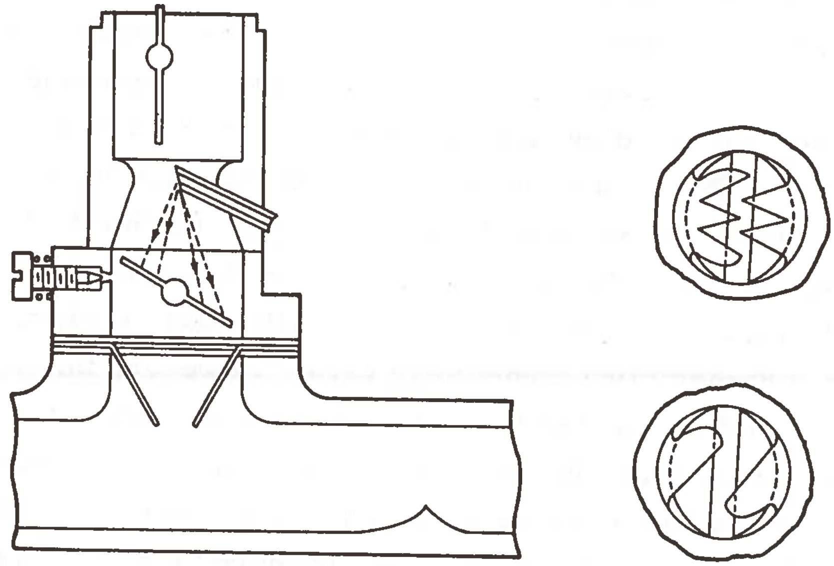


Figure 3-37b. Air/Fuel Mixture Deflection Device Installation

Performance data for the Hydro-Catalyst, the Kolb Vaporizer, and the Spartan II device are shown in Tables 3-11 and 3-12 and in Figures 3-38 and 3-39. Driving-cycle-based data for the Wieseman deflector device were not available.

There are several sources of recent data on the performance of the Hydro-Catalyst device. As shown in Table 3-11, EPA ran 1972 FTP tests of this device on a 1972 Cadillac Eldorado, with and without CD ignition (Ref. 3-60). No baseline tests were conducted; results were compared with 1973 certification data for this vehicle. With standard ignition, a significant increase in fuel economy was observed along with improvement in CO, but NO_x emissions doubled and HC emissions increased 50%. The same emissio trends were observed in a Scott Laboratories test of a 1973 Ford Mustang. Fuel economy results for this vehicle indicate a 34% improvement. Ignition timing for this test was advanced to 13° BTDC from the stock vehicle setting of 6° BTDC (Ref. 3-61).

Opposed to these results for fuel economy improvement are the findings of the University of Michigan. Here engine dynamometer tests of the Hydro-Catalyst device installed in a 350 CID engine were run at simulated road load cruise conditions (Ref. 3-62). These results, displayed in Figures 3-38 and 3-39, indicate that the device has a negative effect on fuel economy. Tests conducted by Esso Research on two different vehicles (1971 Chevrolet and 1965 Dodge) also indicate a slight increase in fuel consumptio

There are no reliable fuel economy data for the Kolb Vaporizer. The emission data shown in Table 3-11 are based on Scott Laboratorie tests reported in Ref. 3-57 and indicate generally good results for installations on older, precontrolled model year cars. However, this indicated effectiveness is qualified by the fact that a number of engine modifications were made prior to testing, including disconnection of the vacuum advance and adjustment of the idle mixture screws to the leanest possible setting.

Spartan II fuel economy data produced for the developer by a private laboratory are displayed in Table 3-12. These positive results have not been verified by any testing conducted in a certified laboratory facility.

TABLE 3-11. PERFORMANCE CHARACTERISTICS OF "ATOMIZING" DEVICES

Device	Vehicle Tested	Testing Organization		Fuel Economy mpg	Pollutant Emissions gm/mi		
					HC	CO	NO_x
Hydro-Catalyst	1972 Cadillac Eldorado Test #1 (No EGR, CD Ignition)	EPA, Emission Control Technology Div., Office of Air and Water Programs 1972 FTP	With	9.32*	2.56	8.91	4.05
	Test #2 (EGR, CD Ignition)		With	8.82*	3.09	8.63	2.96
	Test #3 (EGR, Coil Ignition)		With	10.87*	3.25	8.84	5.90
			1973 Certification Data	8.1*	1.9	19.0	2.4
	1973 Ford Mustang 302 CID	Scott Laboratories 1973 FTP	Without	10.69	2.46	35.66	3.07
			With	12.54	2.61	16.63	3.41
			% Change	34.0	6.1	-53.2	11.1
R. G. Kolb "Vaporizer"	1966 Pontiac 389 CID	Scott Laboratories for Developer 1970 FTP	Without		8.55	51.7	3.4
			With		3.82	52.4	2.3
			% Change		-55.0	1.0	-31.0
	1963 Dodge 235 CID	Scott Laboratories for Developer 1970 FTP	Without		3.96	73.73	5.06
			With		3.46	58.60	2.93
			% Change		-13.0	-20.0	-42.0

*Carbon Balance Method

TABLE 3-12. PERFORMANCE CHARACTERISTICS OF THE SPARTAN II DEVICE, FUEL ECONOMY

Device	Testing Organization	Speed	Mpg Without Device	Mpg With Device	Percent Increase
Spartan II 1974 Ford 400 CID	Ronnie Kaplan Engineering Inc.	City Driving	11.5	14.9	29.5
		50 mph	15.2	20.5	34.9
		55 mph	15.4	19.7	27.9
		60 mph	15.3	17.7	15.7

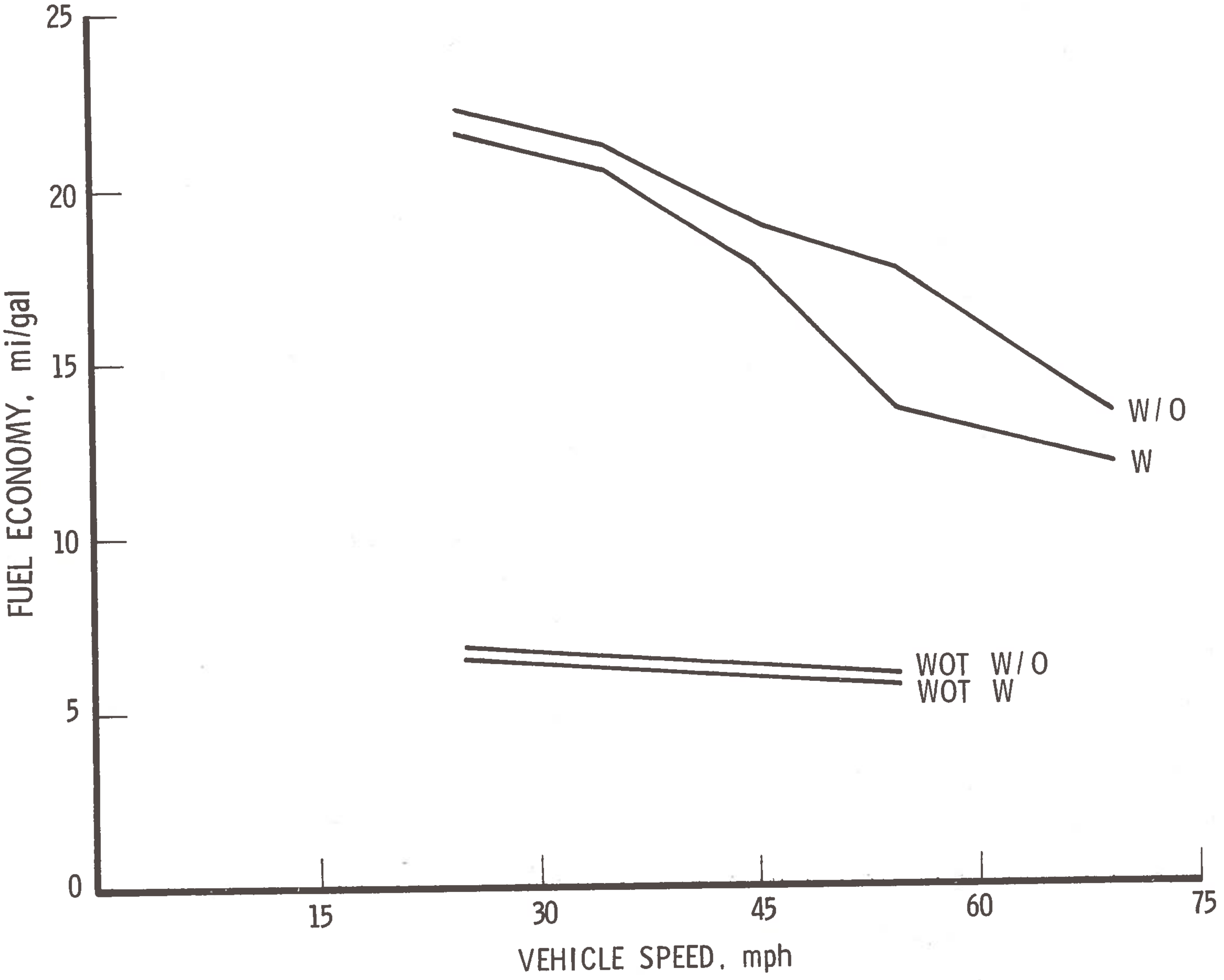


Figure 3-38. Fuel Consumption with the Hydro-Catalyst Device (Ignition Timing 4° BTDC)

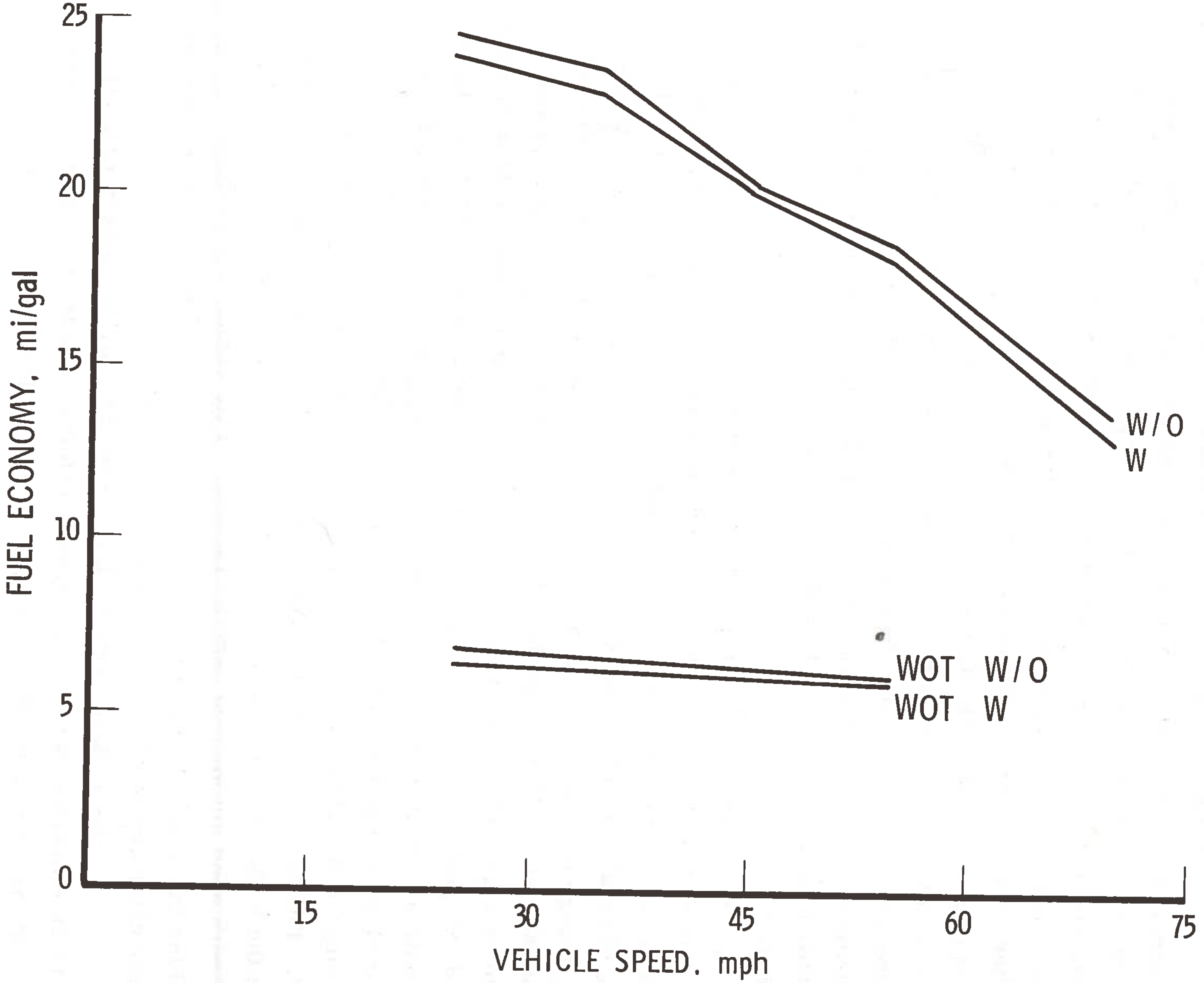


Figure 3-39. Fuel Consumption with the Hydro-Catalyst Device (Ignition Timing 11° BTDC)

Table 3-13 provides a summary evaluation of mechanical atomizers. Because of the simplicity of these devices, installation time and cost are low, and maintenance requirements are minimal. For the same reason, production rates sufficient to meet demand can be achieved. Availability of the Hydro-Catalyst at present is limited, because production rates have been slowed due to difficulties with acceptance of the device by government agencies including the California Air Resources Board. The Spartan II device is going into production, and an advertising and marketing campaign is under way. However, this device has not been certified in California. The development and production status for the Kolb Vaporizer and the Wieseman deflector have not been established. These devices are believed to be experimental.

The available test data on mechanical atomizers are meager, show mixed results for fuel economy and emissions, and do not provide a sound basis for an evaluation of performance for devices of this kind. However, several theoretical considerations suggest that none of these systems offer enough promise to warrant further investigation or testing in this study. In the case of the Hydro-Catalyst device, the claim made that the apparatus produces a particle-charging action appears to be unfounded. It is well established (cf. Refs. 3-63 and 3-64) that a much higher voltage than that obtainable with a simple wet cell (if indeed the device operates as a wet cell) is required to charge fuel particles. Non-conducting particles also require a high voltage for charging; for example, as required in gas cleaning equipment. Furthermore, the objective of the charging process, which is stated to be the collection of fuel particles on the manifold walls, appears to be at odds with good automotive design practice. This seeks to prevent fuel from reaching the manifold walls where it tends to flow as a fluid film and results in poor distribution of the fuel charge.

As a class, screen devices might provide some beneficial effects on emissions due to vaporization effects provided by the screen surface. In the case of the Vaporizer, it is impossible to tell from the test

TABLE 3-13. EVALUATION SUMMARY FOR MECHANICAL ATOMIZERS

1. Degree of Fuel Economy Improvement	Probably negligible
2. Kit Content	Configurations vary, but they usually consist of a screen or a fuel mixture deflector device which fits between the carburetor and manifold. Devices are tailored for specific carburetor requirements; i.e., no. of barrels, and the bolt hole configuration. Cost: Spartan II - \$30 to \$35, Hydro-Catalyst - \$28.
3. Mass Producibility	Thousands/week/manufacturer
4. Availability	Production of these items is very limited at this time. Hydro-Catalyst production and sales nearly stopped due to excessive advertising claims and difficulty with EPA and CARB. Hydro-Catalyst is about ready to resume production again. Spartan II is in production but not yet authorized in California. The Kolb Vaporizer and Wieseman deflector are experimental devices.
5. Installation Requirements	Very simple, but it should be performed by a trained mechanic, since carburetor removal is required.
6. Installation Time and Cost	0.5-0.75 hr - \$10-\$15
7. Maintenance Requirements	Clean or replace every carburetor cleaning (25,000 mi)
8. Effect on HC, CO, and NO_x Emissions	Data base does not permit assessment
9. Effects on Vehicle Power, Driveability	Reported poor cold-start characteristics, possible power attenuation at high speeds
10. Types of Data Available	One set EPA emissions tests for Hydro-Catalyst, balance developer-furnished data on emissions and fuel economy
11. Reliability of Data Base	Poor as a whole due to source and sample size

data if the improvement in emissions is due to the screen or to the timing and air/fuel mixture adjustments made prior to testing. There is some evidence to indicate that the screens may act to restrict flow at high engine loads, and at least one of these screen devices (the Spartan II) is designed with a central opening in the screen mesh intended to relieve this problem.

In view of these considerations and the lack of substantiating data from authoritative sources supporting the claims for improved fuel economy, it is not recommended that these devices be included in a follow-on test program.

3.4 LEAN-BLEED DEVICES

There are large numbers of lean-bleed devices now on the market or under development. Representative of these are the Adaks Vacuum Breaker; the Albano device, which is marketed under several names including Air Jet, Mini-Turbo charger, H. P. Air Injector, Variable Combustion Meter and the Power-On Gas Saver; the Ball-Matic device; the Pollution Elimination Device (PED); and the STP Modulating Air Bleed. The Ball-Matic device was formerly the Air-Flow-Matic. Figures 3-40 through 3-43 depict some of these devices.

The basic principle of operation of these devices is quite simple. They consist of an air valve which is designed to open under certain prescribed conditions of manifold vacuum. This valve is connected to the intake manifold, usually through the PCV line. Opening of the valve allows ambient air to be drawn into the manifold where it mixes with and leans out the normal air/fuel mixture provided by the carburetor. This addition of air is claimed to improve fuel economy and to reduce HC and CO emissions by promoting more complete oxidation of the combustion products.

The flow characteristics of these devices as a function of manifold pressure vary somewhat with the bleed valve design and the physical arrangement of the apparatus. The STP device, for example, is a flow-modulated design in which the bleed flow through the valve is governed by the pressure difference between the carburetor ported vacuum supply and

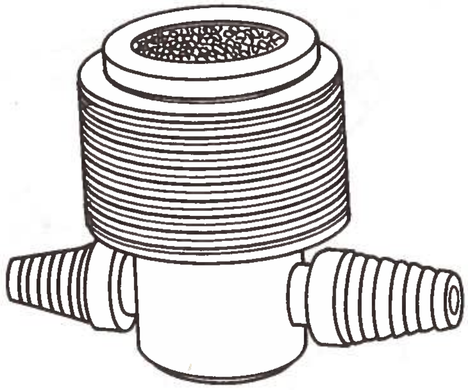
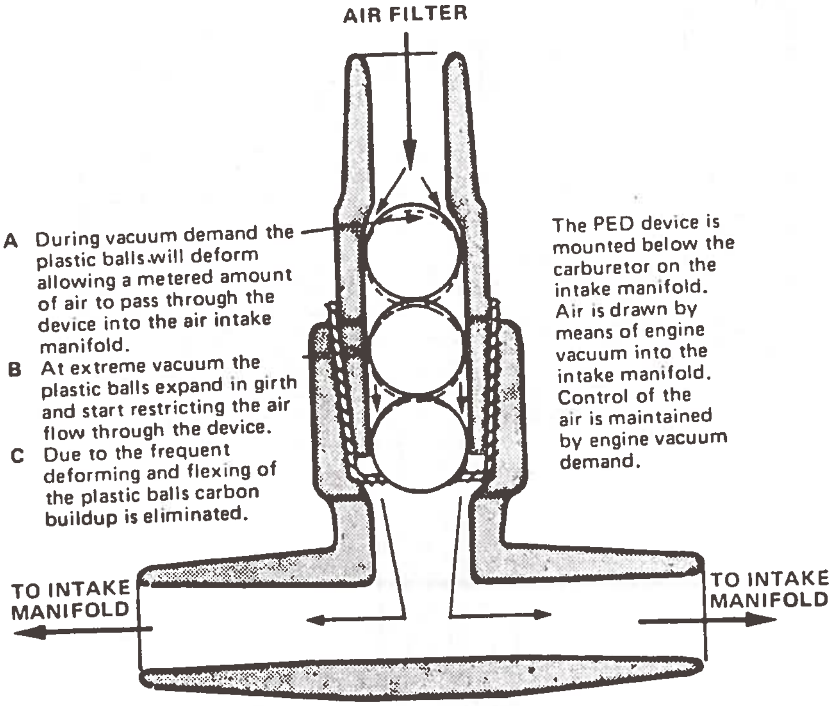


Figure 3-40. Albano Air Jet



A During vacuum demand the plastic balls will deform allowing a metered amount of air to pass through the device into the air intake manifold.

B At extreme vacuum the plastic balls expand in girth and start restricting the air flow through the device.

C Due to the frequent deforming and flexing of the plastic balls carbon buildup is eliminated.

The PED device is mounted below the carburetor on the intake manifold. Air is drawn by means of engine vacuum into the intake manifold. Control of the air is maintained by engine vacuum demand.

PED device illustrated here confines plastic balls between two metal collars at top and bottom. Air bleed is controlled by either tightening or loosening the tube containing the balls into the threaded base. Air filter is a foam plug.

Figure 3-41. Pollution Elimination Device (PED)

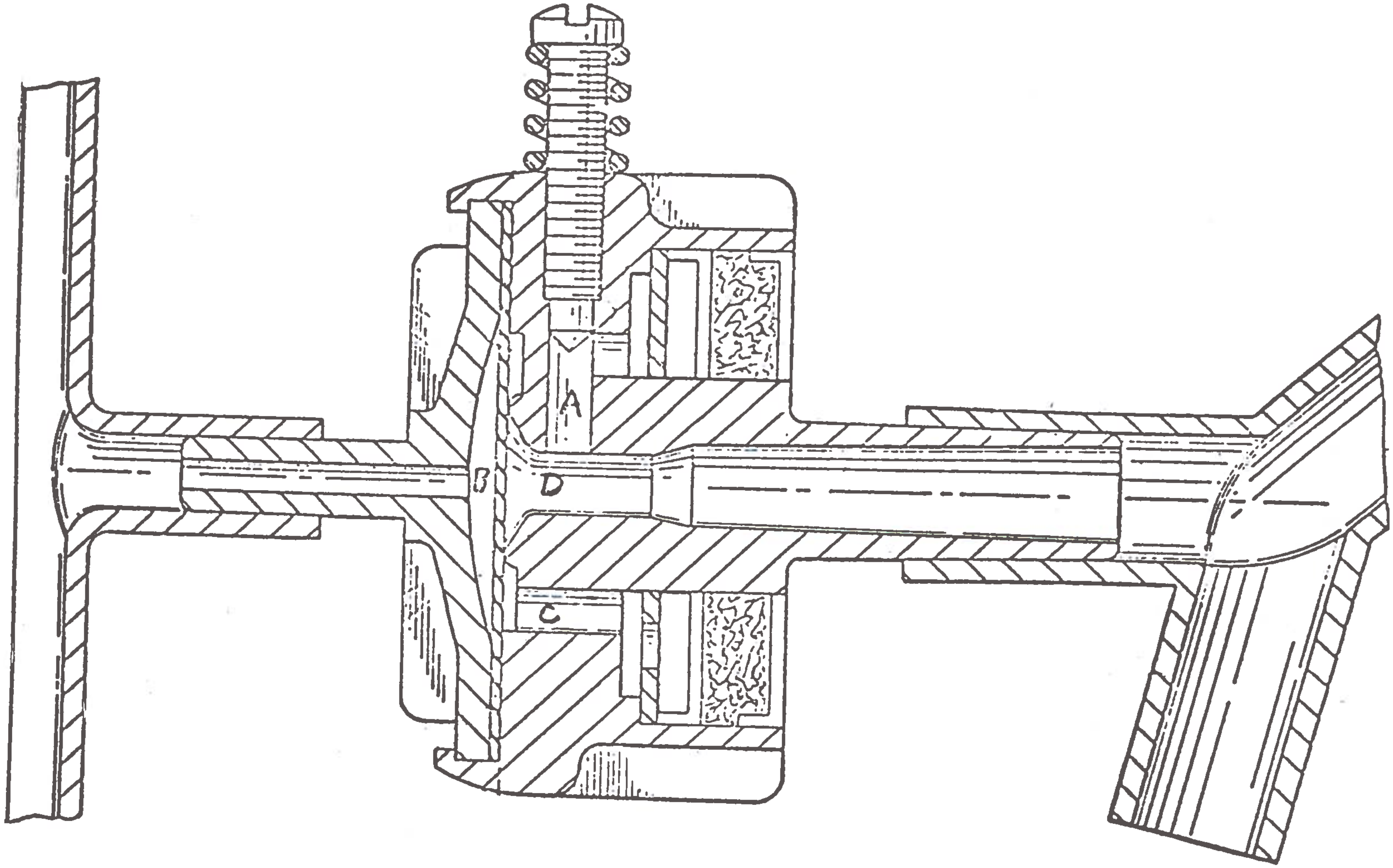


Figure 3-42. STP Modulating Air Bleed

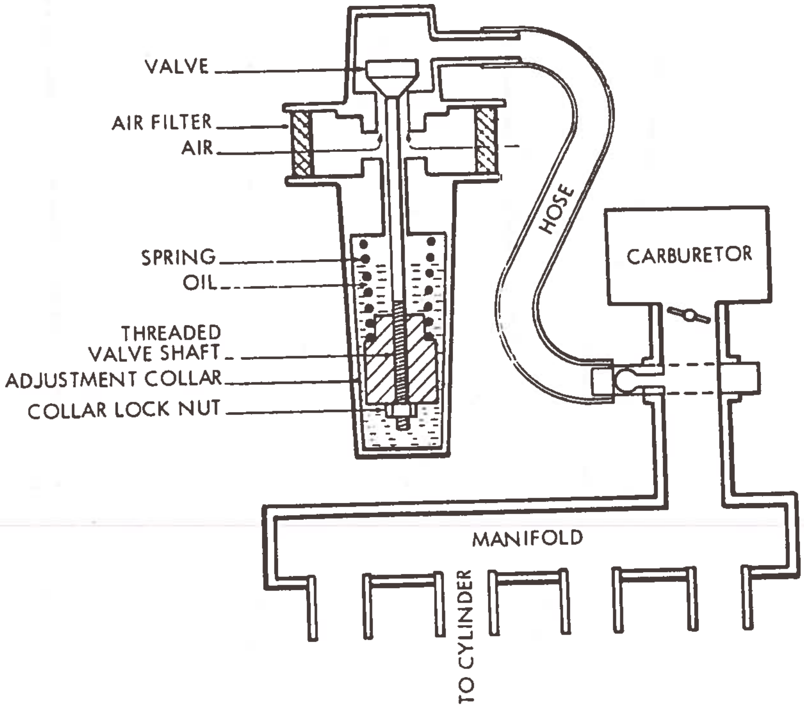


Figure 3-43. Adaks Vacuum Breaker Functional Schematic Diagram

the engine intake manifold. The Adaks device, pictured in Figure 3-43, is unmodulated and operates directly in response to manifold vacuum. In spite of these differences, air bleed devices as a group operate in a generally similar manner with respect to vehicle operating mode. That is, bleed flow occurs at high and intermediate manifold vacuums associated with deceleration, idle, and low-cruise-power conditions, with little or no flow at high power and WOT conditions. An exception to this is the PED shown in Figure 3-41, wherein the valving action appears to restrict air bleed at the high vacuum conditions associated with deceleration and idle. The Air Jet device may also operate in this manner.

The flow characteristics for the Adaks design are shown in Figure 3-44. The maximum bleed flow of 3 to 4 scfm is typical of the relatively low bleed flow rates utilized in these devices. This rate, although low, can result in an air-fuel ratio mixture increase of approximately one

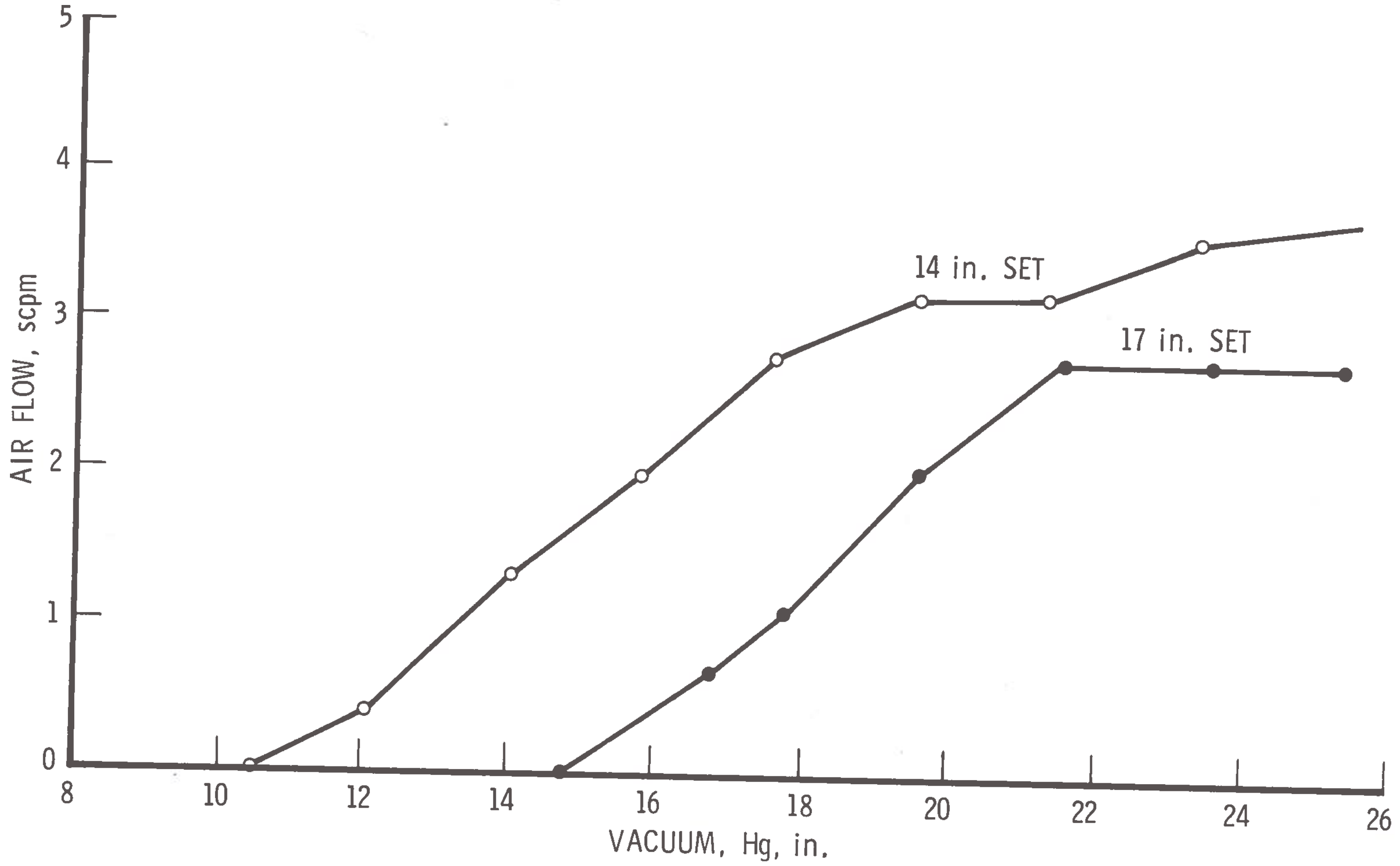


Figure 3-44. Flow Characteristics, Adaks Lean-Bleed Device

(e.g., from 15 to 16) at low power cruise conditions (e.g., typical carburetor air flow rates are ~50 CFM at 45 mph).

It appears that many of the lean-bleed systems were originally developed and introduced to the market as devices designed to reduce exhaust emissions. With the advent of the fuel crisis and the growing national emphasis on automotive fuel economy, the claims made for these systems have stressed fuel economy benefits as well. Claims of fuel economy improvement in many cases are greater than 10% and range up to 25%.

Such claims are usually based on performance benefits associated with improved combustion at lean mixture conditions. The PED is stated to provide additional combustion benefits by delivering the bleed air in an oscillatory flow pattern induced by the vibrating action of the plastic balls used in the bleed valve mechanism (see Figure 3-41). This device is currently being tested by an agency of the Canadian government, the Fuels Research Centre of the Department of Energy, Mines, and Resources in Ottawa, Canada. The principal investigator in this test program reports that the pulsating motion of the flow has been observed and probably contributes to the fuel economy improvement measured with this system (Ref. 3-65). However, no evidence confirming this theory has been developed.

Table 3-14 summarizes the available data on the emissions and fuel economy performance for the Adaks, Albano, and STP devices. It is extremely difficult to identify a consistent level of performance improvement based on this small sample. These data are representative of lean-bleed test data generally available in that they reflect the wide variability of results from vehicle to vehicle. This variability is especially marked in the data on fuel economy, where the effect of the devices ranges from -3% to +12%. The average of the cold-start FTP test results suggests an improvement in fuel economy of about 2%, primarily reflecting the performance of the Adaks device. The data on emissions are somewhat more consistent in trend, indicating that lean-bleed devices applied to 1963 through 1970 model year cars significantly reduce CO emissions (40% to 70%) and in some cases may also reduce HC and NO_x emissions.

TABLE 3-14. PERFORMANCE OF LEAN-BLEED DEVICES

DEVICE	AUTOMOBILE	TESTING ORG. TEST CYCLE		PERFORMANCE FUEL ECONOMY MPG	HC GR/M	CO GR/M	NOx GR/M
ADAKS	1963 Chevrolet 283 CID	EPA 1972 FTP	Without	14.56*	8.3	113.8	1.55
			With	14.06*	7.1	78.1	1.45
			% Change	-3.5	-14.0	-31	-7
	1970 Plymouth Valiant 225 CID	EPA 1972 FTP	Without	17.39*	2.8	48.0	6.3
			With	18.55*	1.8	11.8	7.5
			% Change	6.7	-36	-75	-19
	1970 Plymouth Valiant After 2000 mi. with device	EPA 1972 FTP	Without	--	--	--	--
			With	--	1.5	10.7	5.8
			% Change (from baseline)	--	-46.4	-77.7	-7.9
	1965 Plymouth Fury 225 CID	New York City Dept. of Air Resources 1972 FTP	Without	16.9	4.1	43.2	7.6
			With	16.6	3.8	12.0	7.2
			% Change	-2.2	-8.1	-72.3	-4.9
	1965 Plymouth Satellite 225 CID	New York City Dept. of Air Resources 1972 FTP	Without	19.3	2.4	26.8	9.0
			With	21.7	1.8	13.5	7.4
			% Change	12.7	-22.8	-49.7	-18.0
ALBANO	1969 Ford Fairlane 250 CID	New York City Dept. of Air Resources 1972 FTP	Without	17.45	1.9	19.6	7.1
			With	17.94	2.0	8.4	6.7
			% Change	3	2	-57	-6
	1970 Valiant 225 CID	EPA 1972 FTP	Without	--	2.0	30.6	5.9
			With	--	2.0	27.5	5.9
			% Change	--	0	-10	0
STP	Average of 5 cars 1964-71 280 CID to 383 CID	Scott Labs 1972 FTP Hot Start	Without	17.0	3.7	30.5	5.0
			With	17.4	3.2	10.3	4.9
			% Change	2.1	-11.7	-66.1	-2.2

* Calculated, using EPA Carbon Balance Equation

TABLE 3-14. PERFORMANCE OF LEAN-BLEED DEVICES (Concluded)

DEVICE	AUTOMOBILE	TESTING ORG. TEST CYCLE		PERFORMANCE			
				FUEL ECONOMY MPG	HC GR/M	CO GF/M	NOx GR/M
STP cont'd.	Average of 64 Ford 289 CID & 65 Dodge Dart 273	Scott Labs 1972 FTP Hot Start	Without With % Change	18.3 19.2 4.5	4.4 3.7 -16.4	34.9 7.7 -78.1	5.6 5.3 -6.2
	Average 5 cars '68 Ford Fairlane, 302 CID 64 Ford Galaxie, 289 CID 68 Fury, 383 CID 65 Dodge Dar, 273 CID 71 Chev. Camaro, 350 CID	Scott Labs. 30 mph Steady State	Without With % Change	24.05 25.10 4.3	197 ppm 165 ppm -16.2	0.50% 0.18% -64.0	1292 ppm 648 ppm -49.0
		60 mph Steady State	Without With % Change	15.98 17.83 11.5	145 ppm 91 ppm -37.2	0.91% 0.41% -55.0	2543 ppm 2673 ppm -0.5
		1972 FTP Hot Start	Without With % Change	16.01 16.23 0.22	3.66 3.25 -11.20	26.98 10.32 -61.60	5.03 4.88 -3.0

Additional data on the Adaks device operating over an extended period are given in Table 3-15. The data shown are average values for several light to heavy duty trucks tested by the New York City Department of Air Resources (Ref. 3-66). The results indicate a consistent improvement in fuel economy of about 5%. The emission performance is mixed, indicating good reductions in CO and significant increases in HC and NO_x for some of the vehicle classes tested. Similar HC and CO test results were obtained in seven-mode hot-start tests conducted by the California Air Resources Board (Ref. 3-67).

TABLE 3-15. ADAKS DEVICE PERFORMANCE OVER AN EXTENDED PERIOD, NEW YORK CITY DEPARTMENT OF AIR RESOURCES

Vehicle Weight Class	Number of Vehicles	Average Test Mileage	Fuel Economy Percent	Emission Change Percent		
				HC	CO	NO_x
6-10,000 lb	3	2206	4.9	6.5	-25.9	-5.3
10-26,000 lb	3	297	4.5	28.5	-68.1	17.4
>26,000 lb	1	3600	5.6	-37.7	-81.1	4.1

With regard to the PED, fuel economy data were available only by telecon with the Fuels Research Center (FRC) in Ottawa, Canada (Ref. 3-65). For 3 cars tested at steady speed, the fuel economy improvement was observed to range from 12% to 17%. Based on these results, the FRC is installing the PED on 23 additional cars to obtain performance for a larger sample size.

Two potential problems associated with the use of lean-bleed devices are:

a. Increased exhaust temperatures which can contribute to engine overheating and shorten valve life, and

b. Degradation in vehicle driveability.

Engine temperature effects with the PED were tested by the Canadian FRC facility and were found to be negligible. The Adaks device, as reported in

Ref. 3-68, showed an increase in exhaust manifold temperature at low speeds where the air-bleed device is operative, but had essentially no effect at higher road loads where long-term temperature effects could be significant. Concerning driveability, tests conducted by Olsen Laboratories on the Adaks device (Ref. 3-68) indicate that stalling during cold start, stumble during acceleration, and reduced acceleration performance were frequent occurrences for most cars tested. In mileage accumulation tests conducted by EPA on a Plymouth Valiant equipped with the Air Jet device (Ref. 3-69), there was no evidence of degraded driveability.

The cost of the devices described herein are $40-48 for the Adaks, $20 for the STP device, and $9.75 for the Albano device. Installation costs are expected to be minimal for those devices which are inserted in the PCV line, requiring no more than one hour of labor (Ref. 3-68). Installation of the Adaks device requires a manifold adapter to be installed, necessitating the removal of the carburetor and thereby involving a higher installation cost (3-4 hours labor is estimated in Ref. 3-69).

An evaluation summary for lean-bleed devices is provided in Table 3-16. By reason of their simplicity, these devices are not expected to present major problems with respect to mass producibility, availability, applicability, and maintenance. They are easily mass producible in quantities of thousands per week, they are available on a nationwide basis, and a number of manufacturers are presently competing for the available sales market. Maintenance requirements are minimal, simply requiring periodic inspection and cleaning similar to PCV valves. There are no known restrictions on applicability, except those specified by the CARB for those devices tested and granted exemptions under Section 27156 of the California Vehicle Code. Ref. 3-70 indicates that the CARB has granted exemptions to the Ball-Matic and Air Jet devices, with restrictions relating to their use on older model cars (1970/1971 model years and older) and, in the case of a discontinued version of the Ball-Matic device, use on engines over 140 CID.

In summary, it appears that the average fuel economy improvement that can be expected from lean-bleed devices is minimal. The quantity

TABLE 3-16. EVALUATION SUMMARY FOR LEAN-BLEED DEVICES

Fuel Economy Improvement	2%-5% increase
Kit Content	Vacuum-operated air metering valve, air-bleed hose, air filter
Mass Producibility	Several thousand per week per manufacturer
Availability	Now available on a nationwide basis
Applicable Models	Basically applicable to any carbureted engine but restricted in California (in most cases) to older model years and engines larger than 140 CID
Installation Requirements	Extremely simple but should be installed by a trained mechanic to make sure valve as well as carburetor and ignition settings are adjusted properly
Installation Time and Cost	1-1.25 hr, \$15-\$20
Maintenance Requirements	Filter change at every 12,000 miles, inspection of valve, etc.
Effect on HC, CO, and NO_x	Test data indicate reductions in emissions (sometimes significant, especially in CO) but when CO is lower, NO_x often increases
Effect on Vehicle Power, Driveability	Reduces power, driveability to a small extent by causing some stalling and rough idle; increases acceleration times slightly; causes harder starting
Types of Data Available	EPA, CARB emission and fuel economy tests; mfr.-sponsored tests by auto testing labs; and individual testimonials
Reliability of Data Base	Good with regard to state and federal agency tests, but there is no systematic evaluation of engine-variable influences

of bleed air used in these devices is extremely small and is not expected to influence air-fuel ratio significantly except at the low air flow rates associated with idle, deceleration, and low cruise power conditions.

There is wide variability in the results of fuel economy and emissions tests, and it appears that some developers are basing their claims of 10% to 20% improvement on some of the more extreme test results observed. Lean-bleed devices do appear to be consistently beneficial in reducing CO emissions but are erratic in performance with respect to HC and NO_x. The greatest improvements in fuel economy and emission reductions are to be expected on precontrolled cars where rich mixture settings lend themselves to improvement by the technique of leaning. Unless the developers of these devices can furnish additional performance data which show substantial and consistent improved performance, it is recommended that these devices not be included in the test phase of this program.

3.5 VAPOR INJECTORS

Vapor injectors have been available for many years, but the recent fuel shortage has resulted in a proliferation of these devices. Presently, there are at least 10 different devices on the market, and some of these are being sold under more than one name. The basic mode of operation is the same for all these devices; differences exist in the formulation of the fluid used or in design details, such as the configuration of the air intake valve and the type of fluid container used.

Vapor injectors usually consist of a container holding a water solution of alcohol plus other organic additives. The fluid is evaporated or entrained as fine droplets by air taken in through a valve in the top of the container and passed through an aeration device inserted in the liquid. Injection into the intake manifold usually takes place through the PCV line, with the motive force provided by the differential pressure between ambient and manifold vacuum. A typical device, the Econo-Mist Vapor Injector, is illustrated in Figure 3-45.

The term "vapor injector" is somewhat of a misnomer, since the system actually injects a combination of vapor and an aerosol mist. The

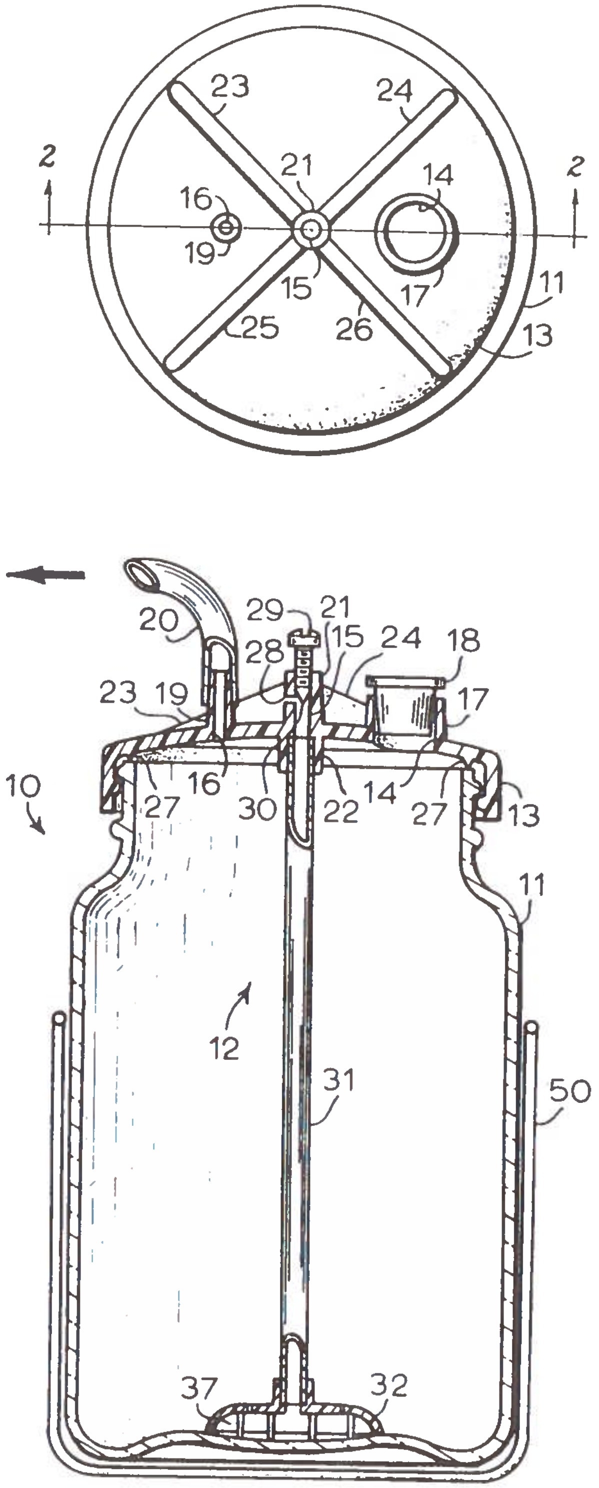


Figure 3-45. The Econo-Mist Vapor Injector (Representation from Patent)

injected vapor (or aerosol) mixes with the air/fuel mixture from the carburetor and, it is claimed, acts to produce better atomization of fuel droplets and more even distribution of the mixture to the engine cylinders. These, as well as other effects discussed below, are purported to result in better combustion efficiency and, consequently, improved fuel economy and reduced emissions. Improvements in fuel economy up to 20% are claimed.

Table 3-17 provides some product information concerning the vapor injector devices examined in this investigation. It will be noted that some of these devices have been sold under more than one name. Also some devices are related in that they are offshoots of earlier devices which are still being produced. For example, the Lift Device was originally the Turbo Vapor Injector (TVI). The partners in the manufacture dissolved their relationship and proceeded to manufacture and market the vapor injectors independently.

No really significant differences were found in any of the devices about which information was obtained. Each manufacturer claims he has an innovation that makes his device superior to the rest. It appears, however, that these are the usual marketing claims. The biggest differences seem to be in design details, as stated previously; i.e., fluid composition, container shape and material, inlet valves, and aeration systems. Generally, most of the devices operate with a fixed inlet setting; vapor flow rate varies more or less directly as a function of manifold vacuum. The VIC 500 "metering valve" is an exception, however. This valve is spring loaded, and the opening varies as a function of manifold vacuum, with the maximum air intake of about 2 cfm occuring at low vacuums from 2 in. to 8 in. Hg. The flow is reduced to about 1 cfm at and above 8 in. Hg. The manufacturer claims that this valve delivers more vapor during acceleration "when you need it" than competitive injectors. The VIC 500 formerly was used in conjunction with idle air bleed screws, but these have been discontinued, apparently because they were found not to contribute any additional benefits.

A number of theories have been offered by the manufacturers as to why vapor injectors might work to improve combustion efficiency. None of these provide a sound physical or thermodynamic justification for

TABLE 3-17. VAPOR INJECTOR PRODUCTS

DEVICE	MANUFACTURER/DISTRIBUTOR	AIR FLOW RESPONSE CHARACTERISTICS	INJECTANT FLUID
Mach III Vapor Injector	Advanced Mobile Products Farmington, Michigan	Unknown	Unknown
Monarch Vapor Injector	American Mobile Products Detroit, Michigan	Unknown	Water, methanol, other organics
Mark II Vapor Injector	APO International, Inc. Dallas, Texas	Directly proportional to manifold vacuum, adjustable setting	Water, methanol, other organics
VIC 500 Vapor Injector (formerly Frantz Vapor Injector)	Amtech, International Lewiston, Idaho	Modulated as function of manifold vacuum; max flow at low vacuum, one half max at high vacuum	Water, methanol
Scatpac	Cedar Rapids Engineering Co., Cedar Rapids, Ia.	Unknown	Unknown
Econo-Mist Vapor Injector	FAP Corp., Albuquerque, N. M.	Directly proportional to manifold vacuum, adjustable setting	Water, methanol plus proprietary ingredients
Fuel Booster	Manfredi Enterprises, Cleveland, Ohio	Unknown	Water
Water Vapor Power Energizer	Plastic Signs, Inc. Van Nuys, Calif.	Unknown	Unknown
LIFT Fuel Efficiency System, VEEP	St. Clair Sales & Dist. Co., Mt. Clemens, Michigan	Directly proportional to manifold vacuum, fixed setting	Proprietary formulation of organics
Turbo Vapor Injector Hilton Vapor Injector	TVI Marketing, Inc. Bloomfield Hills, Mich.	Directly proportional to manifold vacuum, fixed setting	Proprietary formulation of organics, isopropyl alchohol base

the effects claimed. Obert (Ref. 3-71) provides some insight on the processes involved, stating that "conceivably a small amount of water (or alcohol), well atomized, might decrease the compression work, compression temperatures, and preflame reactions and aid the combustion process." In addition, a number of investigators have postulated that the presence of water vapor in the fuel charge tends to suppress flame velocities and temperatures, thus avoiding energy losses due to auto ignition and knocking. This would also tend to support one of the major claims of vapor injector manufacturers: that the use of vapor injection allows the average automobile engine to be run on one grade lower octane gasoline.

The decrease in compression work required would be a consequence of a reduced temperature ratio over the compression stroke due to the latent heat required for vaporization of the aerosol mist. The magnitude of the effect undoubtedly depends on the concentration of aerosol injected, and it is not clear at this time what concentration yields maximum performance.

The only explanation advanced for the claims made on improved fuel distribution is one given by APO International, manufacturers of the Mark II Vapor Injector. They suggest that the acetone in the Mark II fluid tends to reduce the surface tension of the incoming fuel droplets, allowing them to be more easily broken up and atomized. This would promote better distribution of fuel to the cylinders, since finer droplets are more easily entrained in the turbulent air stream and there is less tendency for large droplets to migrate toward the manifold walls. APO technicians have observed improvements during vapor injection experiments run while using glass manifolds. They claim to have observed the effect and then to have varied the fluid ingredients until it was determined that the acetone ingredient accounted for this phenomenon. It is also claimed that improved redistribution of the fuel charge in a V-8 Chevrolet engine, due to vapor injection, has been measured. Without the vapor injector, the mixture ratios in each cylinder ranged from 13.1 to 13.9. With the vapor injector installed, the range was reduced to 13.3 and 13.6.

The role of each of the various organic fluid ingredients is not well defined. Generally speaking, most of the fluid formulations contain at least 30% alcohol, with the remainder being mostly water. At a minimum, this serves as an anti-freeze for winter service. It may also enhance performance in a manner similar to the effect of water injection discussed above. In addition, with a small percentage of acetone, it may also serve as a cleaning compound. Other organics and hydrocarbons are sometimes present in small quantities, but their purposes are not defined, since the manufacturers are usually unwilling to discuss their fluid formulations. In one case, the Manfredi Fuel Booster, only water is used; alcohol addition for anti-freeze protection is also recommended. At the other extreme, the Lift Fuel Efficiency Device is recommended for use with a fluid which requires no water dilution, as do some others.

The removal of carbon deposits in the engine is another major claim of the manufacturers. Benefits due to carbon removal are claimed for spark plug life, fuel charge distribution, better ring seating, better compression, and cleaner oil. Finally, the manufacturers claim significant improvements in driveability and reductions in emissions as concomitant effects due to overall improvement in combustion.

Reliable data on fuel economy for vapor injector devices are meager. The available data consist of test reports by government agencies such as the EPA and CARB, a few tests performed by private testing laboratories, and many testimonials (furnished by the manufacturers) on results quoted by private individuals. The testing performed by government agencies treats only a few isolated cases and is by no means exhaustive or systematic with respect to the many variables involved, such as engine size, carburetor and ignition settings. Testimonials were considered unreliable and discarded. Driving cycle test results from government agencies and private laboratories are summarized in Table 3-18. Steady-state, road-load (dynamometer) fuel economy tests conducted by the University of Michigan on the Scatpac system, the Vaporous Extra Energy Producer (VEEP), and a vapor injectant device identified as the Power Foam are shown in Figures 3-46 through 3-48 (Ref. 3-74). Neither the data in Table 3-18 nor the University

TABLE 3-18. SUMMARY OF FUEL ECONOMY AND EMISSIONS TESTS FOR VAPOR INJECTORS

DEVICE	DATA SOURCE TEST TYPE	AUTOMOBILE		FUEL CONSUMPTION OR FUEL ECONOMY	EXHAUST EMISSIONS GM/MILE		
					HC	CO	NO_x
APO Mk II	CARB, Oct. '73	1973 Pinto	Without	1133 gm/test	1.2	13.8	2.1
	Calif. CVS-1	2000 cc.	With	1110 gm/test	1.2	19.2	2.0
	Hot Start		% Change	-2	0	39.2	-5.0
	Feb. '74	1972 Toyota(1)	Without		1.5	10.5	2.9
	Calif. CVS-1	Carina	With		1.6	13.4	2.8
	Hot Start	1588 cc.	% Change		6.7	27.6	-3.5
	Feb. '74	1973 Pinto (2)	Without		1.7	24.0	3.8
	Calif. CVS-1	2000 cc.	With		1.8	29.2	3.6
	Hot Start		% Change		5.9	21.6	-5.3
	DAECO, July '73	1973 Pinto (2)	Without		2.7	44.6	2.8
	1973 FTP	2000 cc.	With		0.7	13.5	2.3
	Hot Start		% Change		-74.0	-69.5	-17.8
			Empty		0.7	14.1	2.4
		1972 Toyota (1)	Without	24.6 mpg	2.4	33.0	3.5
		Carina	With	28.4 mpg	1.9	26.0	3.0
		1588 cc.	% Change	15.4	-20.8	-15.2	-14.2
		1973 Datsun	Without	30.2 mpg			
		1800 cc.	With	30.9 mpg			
			% Change	2.3			
Econo-Mist	Olson Labs, 1973	Not Identified	Without		3.0	16.3	4.3
	1972 FTP		With		2.0	14.3	4.5
			% Change		-33.3	-12.3	4.6
Lift	CARB, Feb. 1974	1973 Plymouth	Without		0.75	11.13	2.55
	1972 FTP	360 CID	With		0.78	6.21	2.67
	Hot Start		% Change		4.0	-44.0	4.7
		1970 Dodge	Without		2.52	35.93	1.56
		318 CID	With		2.49	36.11	1.57
			% Change		-1.1	0.5	0.6

(1) Not the same automobile

(2) Same automobile

TABLE 3-18. SUMMARY OF FUEL ECONOMY AND EMISSIONS TESTS FOR VAPOR INJECTORS (Concluded)

DEVICE	DATA SOURCE TEST TYPE	AUTOMOBILE		FUEL CONSUMPTION OR FUEL ECONOMY	EXHAUST EMISSIONS GM/MILE		
					HC	CO	NO_x
Turbo Vapor Injector	EPA, Mar. '73 1975 FTP	1970 Plymouth 225 CID	Without	19.9 mpg(3)	2.23	32.37	5.07
			With	18.8 mpg(3)	2.13	26.81	6.41
			% Change	-5.5	-4.5	-17.2	26.4
			Empty	19.0 mpg(3)	2.06	28.17	6.12
Frantz (VIC 500)	EPA, Sept. '71 Seven Mode	1968 Ford 200 CID	Without	1100 gm/test	2.7	28	3.7
			With	1100 gm/test	2.8	26	4.0
			% Charge	0	3.5	-7.1	8.1
			Empty	1100 gm/test	2.3	24	2.7

(3) Carbon Balance Method

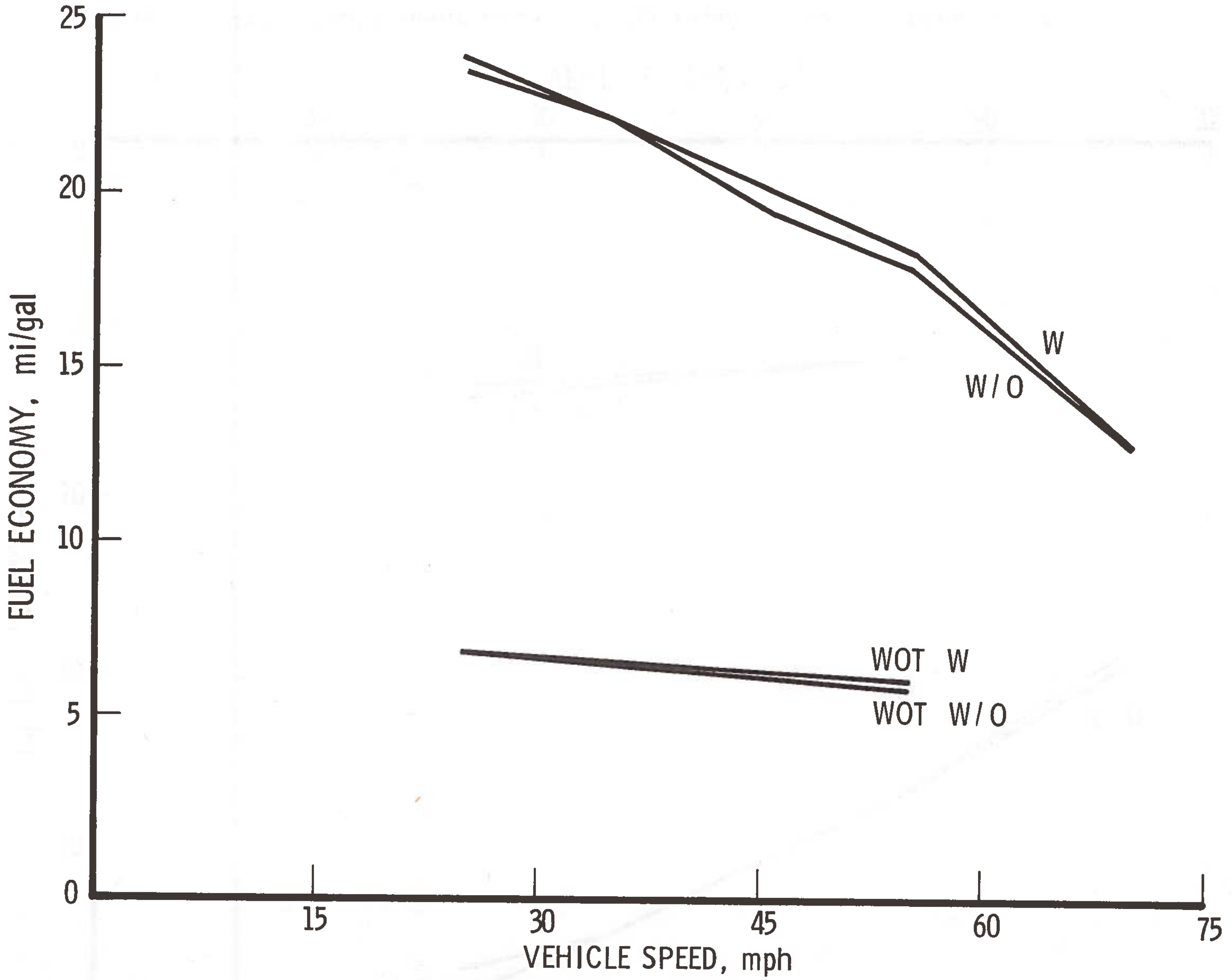


Figure 3-46. Fuel Consumption with the Scatpac System

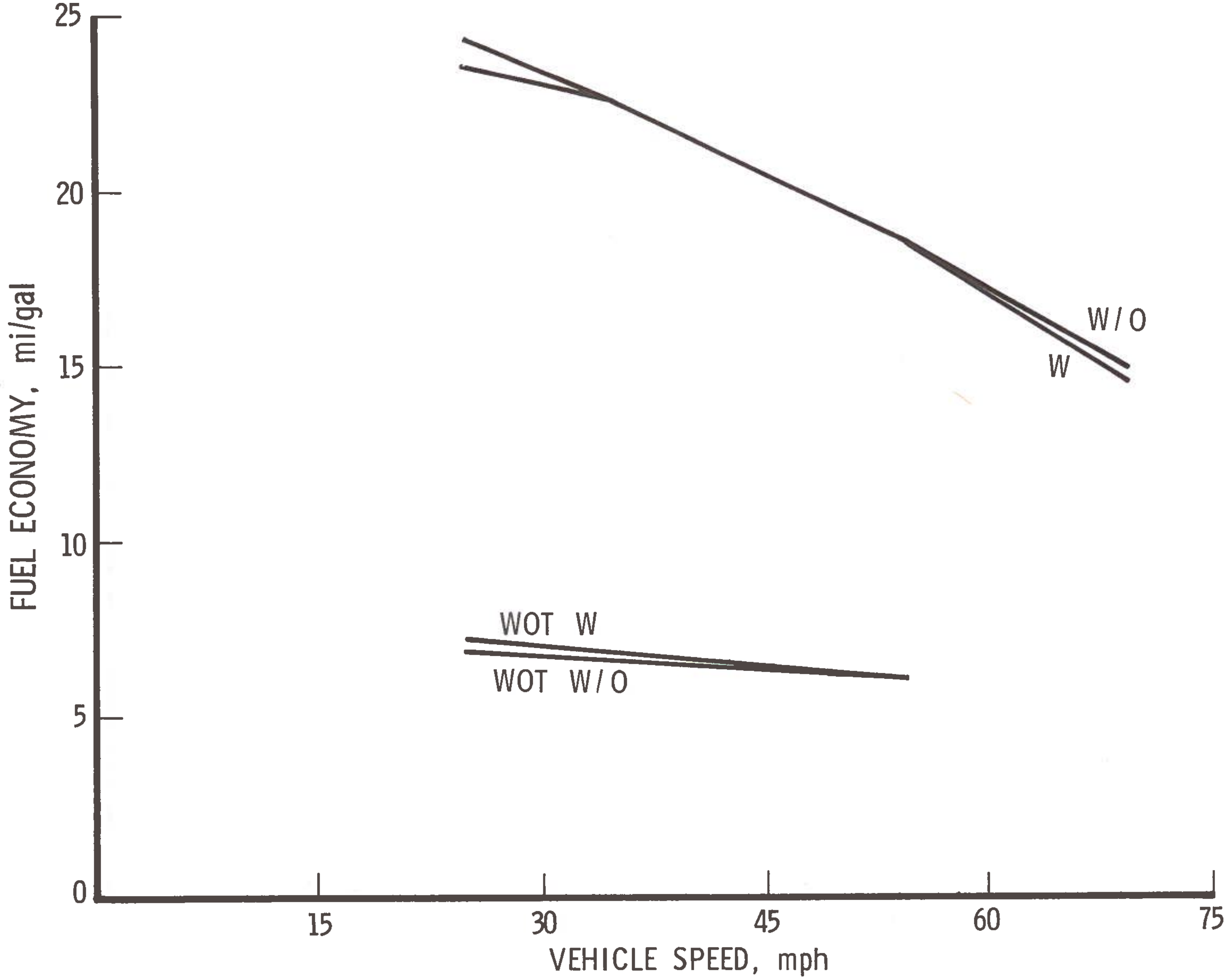


Figure 3-47. Fuel Consumption with the Vaporous Extra Energy Producer

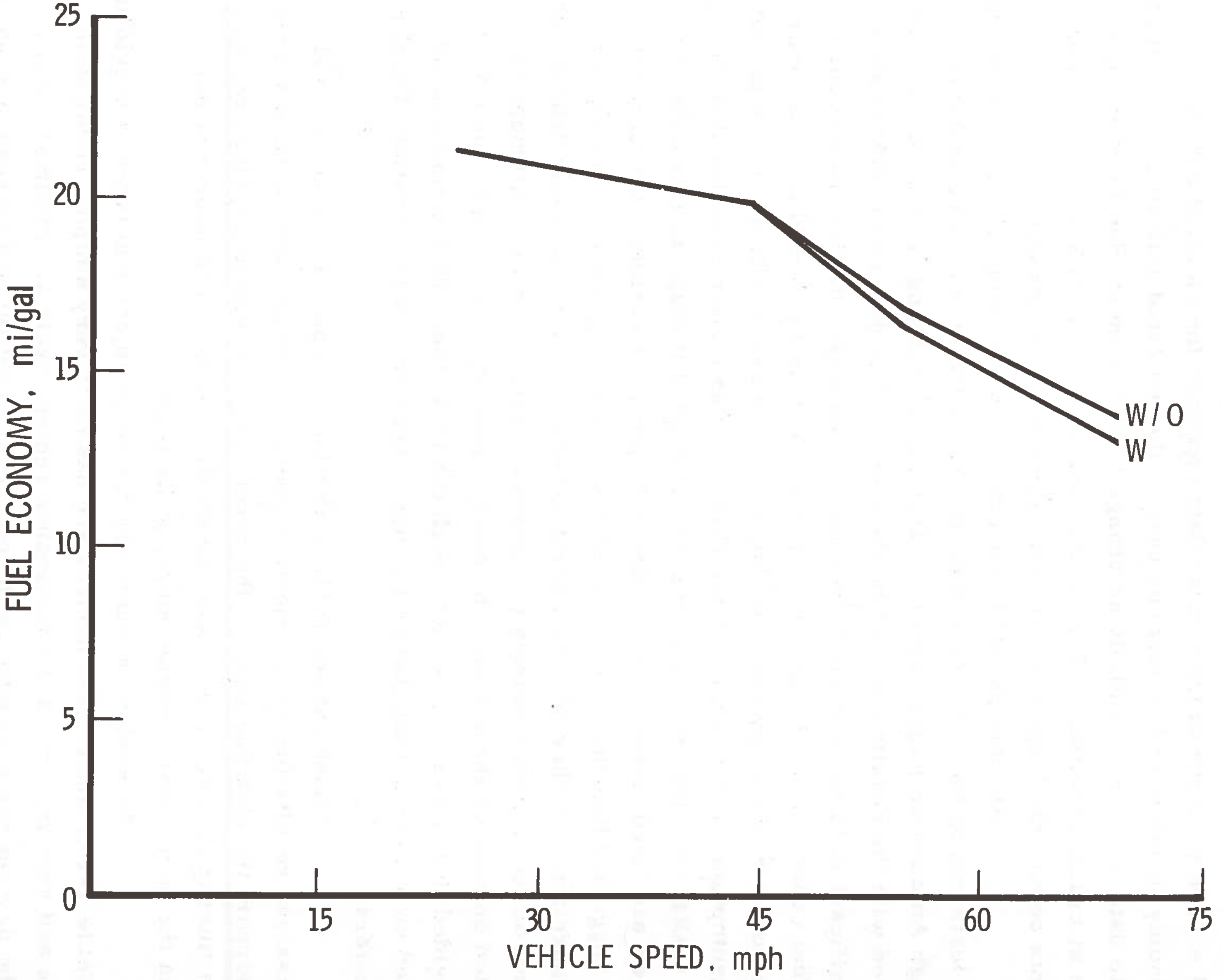


Figure 3-48. Fuel Consumption with the Power Foam Device

of Michigan tests support the claims of the manufacturers with respect to fuel economy. None of the tabular data approach the claim of 20% fuel economy increase and in only one case is the indicated gain 10%. The steady-state data indicate essentially no change in fuel economy due to vapor injection at cruise conditions. Emissions data are mixed, at best; where improvements occur, the largest effects are shown in CO emissions.

An example of the uncertainty in emission effects is shown by the tests run on the APO Mark II device by a private testing laboratory, Daigh Automotive Engineering Co. (DAECO) of Wilmington, California, compared with the results obtained by the CARB. The data from DAECO show significant reductions in emissions and, in one case, distinct improvement in fuel economy. On the other hand, the CARB tests showed that the vapor injector caused a degradation in emissions and essentially no change in fuel consumption. Discussion with the CARB on this matter revealed that during the CARB test, the vapor injector was connected through an idle adjustment screw air bleed rather than into the PCV line as is normal. CARB personnel suggested that this vehicle (Ford Pinto) is very sensitive to change in carburetion, and therefore this arrangement may have had some deleterious effect on fuel mixture causing the increase observed in CO. Although rejected because of these tests, the Mark II was later certified by the CARB provided that it was connected through the PCV line. This action was not based on a specific test, but on previous experience with operation of vapor injectors.

Those data of Table 3-18 which compare fuel economy and emissions results for vapor injectors operated with and without fluid appear to support the idea that most of the benefits may be due to air bleed rather than fluid injection. In one case, emissions results were improved more when the device was operated empty of its fluid.

An evaluation summary for vapor injector devices is provided in Table 3-19. Since these devices are basically very simple, installation time and cost are low, and maintenance requirements are minimal. Many of the devices are presently on the market in quantity, and increased production sufficient to meet demand probably can be achieved. There are no known

TABLE 3-19. EVALUATION SUMMARY FOR VAPOR INJECTOR DEVICES

Fuel Economy Improvement	2%-5% (this assessment) 10%-20% (manufacturers claim)
Kit Content	Injected fluid, fluid container (1-2 qt), intake valve, aerator, intake hose - cost \$30-\$50
Mass Producibility	Several thousand per week per manufacturer
Availability	Readily available now in large cities, could be nationally distributed in a short time
Applicable Models	Generally sold for passenger cars; some restricted in California to larger engines and older model year cars; no known application to diesel engines
Installation Requirements	Basically extremely simple, but installation by a trained mechanic is desirable to insure engine is properly tuned for best operation
Installation Time and Cost	1 to 1.5 hr, \$15-\$22
Maintenance Requirements	Replace fluid when container empties, approximately every 2000 miles; inspect system check valve, aerator for clogging
Effect on HC, CO, and NO_x Emissions	Manufacturers claim significant reductions, especially HC and CO; gov't agency tests show little or no improvement
Effect on Vehicle Power, Acceleration	Manufacturers claim improvements in horsepower, "smoothness" and driveability due to improved combustion
Types of Data Available	EPA, CARB emissions tests on some devices; mfr-sponsored tests by automotive testing labs, both fuel economy and emissions
Reliability of Data Base	Fair to poor; gov't agency tests provide no systematic evaluation of important variables; results from auto testing labs are similarly deficient

restrictions on device applicability, except those specified by the CARB for the devices tested and granted exemptions under the California Vehicle Code. Ref. 3-73 indicates that a number of these devices have been accepted with restrictions on use, with respect to model year and engine size.

The conclusion of this evaluation is that there is little basis for expecting more than a few percent improvement in fuel economy through the use of vapor injector devices. Although the theories of temperature suppression and reduced compression work are quite plausible and beneficial effects may accrue, these effects are probably negligible. Test data provided in Ref. 3-72 show modest benefits with regard to fuel economy and NO_x emissions for gasoline-water mixtures containing 20% water. On the other hand, the typical vapor injector injects about one quart of fluid per thousand miles, a mixture of vapor to gasoline of about 0.4%. It seems highly unlikely that this amount of water, alcohol, or other organic substance could influence the combustion process to the extent claimed. For this reason, the theory of temperature suppression and reduced compression work due to vapor injection as a basis for improved fuel economy should be discounted. Whether or not flame velocities and auto ignition are influenced and reduced is not certain. The most likely cause for improvement in fuel economy and emissions is the leaning of the intake mixture ratio by the injection air. Effects on emissions might be expected to be similar to those displayed by lean-bleed devices; that is, a reduction in CO with variable effects on HC and NO_x. The available test data are meager and do not show consistent trends. Unless the developers of these devices can offer substantially better proof of performance than is presently available, these devices should not be considered for testing.

3.6 FUEL MODIFICATIONS

3.6.1 Introduction

Over the last 10 to 15 years, the development of gasoline additives (special chemicals added to gasoline, usually in trace concentrations) has contributed significantly to improved driveability, maintenance, and durability of motor vehicles. At the present time, all major commercial brands of gasoline contain several such additives to reduce carburetor and engine deposits. Besides additives, a considerable number of other approaches to fuel modification have also been proposed and, in many cases, tested. These modifications fall into one of three categories:

a. Gasoline Additives - The addition of trace amounts (usually between 0.05% and 0.50%) of special chemicals to gasoline

b. Fuel Blends and Emulsions - Blending of water and/or light organics (usually alcohols) with gasoline to form a solution or emulsion prior to storage in the vehicle's fuel tank

c. On-board Mixing of Water and Gasoline - Dispersion of relatively large quantities of water (up to 30% of the mixture by weight) into the gasoline during either carburetion or fuel injection

As is the case in other areas affecting automotive fuel economy, a high level of activity and interest in the fuel areas and the multiplicity of factors which need to be considered in assessing the attractiveness of various fuel modifications have led to many conflicting claims and considerable confusion regarding their potential for energy savings.

3.6.2 Evaluation of the Present Status of Selected Products and Approaches for Fuel Modification

As discussed, various products and approaches have been proposed for the modifications of fuels, to achieve better automotive fuel economy and/or utilization of available crude oil supplies. The present status of selected products and approaches for fuel modification is discussed in the following paragraphs. In general, the particular products and approaches discussed are those for which the most information and data are available.

3.6.2.1 Fuel Additives

The products considered in this section are special chemicals which can be added to gasoline in trace concentrations, either before distribution by the oil company or by the vehicle owner at his convenience.

3.6.2.1.1 Detergent Additives

These additives are intended to remove and/or inhibit the formation of deposits in the various engine systems. It is convenient to separate detergent additives into two classes: (a) carburetor cleaners and (b) dispersants or engine deposit control additives.

a. Carburetor Cleaners. These are the detergent additives used in most gasolines at the present time whose primary function is to remove and/or inhibit deposits in the induction system and carburetor. The chemicals used are phosphates, amides, imidazolines, and esters with molecular weights between 250 and 300. The vaporization characteristics of the additives are such that no function beyond the carburetor is generally claimed for them. They are used in concentrations between 0.01% and 0.05% by volume.

b. Dispersants (Engine Deposit Control Additives). These additives are less likely to be found in commercial gasolines at the present time than the carburetor cleaner additives. The vaporization characteristics of the dispersants are such that they persist in liquid form into the engine and crankcase, and thus can remove and inhibit deposit formation in the cylinders, crankcase, and PCV system, as well as the carburetor. The chemicals used are condensation products of the polyamines (e.g., polybutene amine) and carboxylic acids, with molecular weights in the range 1500 - 3000. Gasoline dispersants are used in concentrations between 0.05% and 0.20% by volume.

There have been several extensive studies of the effect of commercially available detergent additives on vehicle emissions and fuel economy (Ref. 3-75 to 3-77) and numerous tests by EPA and the CARB laboratory of other additive products presented for evaluation by individual inventors and entrepreneurs (Ref. 3-78 to 3-88). The results of the studies and tests do not offer much reason to expect that additional detergent additives beyond those found in most major brand gasolines today will result in significant average fuel economy improvements in the vehicle population. There is little doubt, however, that there are gasolines marketed which cause and/or permit deposits to form in the engine systems and that these deposits can significantly increase fuel consumption and emissions. Hence, if the deposits are removed and/or prevented by the use of a gasoline having effective detergent additives, significant reductions in fuel consumption and emissions can be realized. In these cases, it is necessary to operate the car on the treated fuel for about 500 miles before the detergent additives have cleaned the engine systems. Typical results showing the effect of a dispersant additive on the fuel economy and emissions of a vehicle having accumulated engine system deposits are given in Table 3-20 (Ref. 3-77). The additive used was F-310, marketed by Chevron.

A summary of studies and tests involving detergent additives is given in Table 3-21. For each study/test, the effect of the additive on fuel economy and emissions is noted, as well as the model year and initial emission level of the cars involved in the program. The results given in Table 3-21 are the basis for the previously stated conclusion that further treatment of gasolines with detergent additives would not be expected to have a statistically significant effect on the average fuel economy of the in-use vehicle population.

3.6.2.1.2 Improved Fuel Distribution Additives

A gasoline additive (HTA) which improves the fuel distribution in the induction system of spark ignition engines has been developed and tested by Exxon Corporation. This additive contains a mixture of nonpolymeric amines plus solvent. Its function is to reduce air-fuel ratio variations from cylinder to cylinder during both steady and transient driving conditions. The HTA additive is presently used in all gasolines marketed by Exxon.

TABLE 3-20. EFFECT OF AN ENGINE-DEPOSIT-CONTROL GASOLINE ADDITIVE ON FUEL ECONOMY AND EMISSIONS (Ref. 3-77)

Scott Road Test Program[*]
Fuel Consumption

Test Condition	Percent Increase Over New Carburetor, Nonadditive Fuel	Percent Decrease From Dirty Carburetor, DC Additive Fuel
Federal Exhaust Emission Cycle[**]	5.6	7.7
25 mph - Steady State	14.4	12.6
Idle	26.2	18.2

Scott Road Test Program
Federal Cycle Exhaust Emissions
13-Test Average

	Initial	End of Deposit Accumulation	After 2000 Miles on DC Additive Fuel
HC-NDIR, ppm	258	560	254
HC Change, ppm	---	302	306
HC, % Decrease	---	---	55
CO, %	0.97	2.50	1.60
CO Change, %	---	1.53	0.90
CO, % Decrease	---	---	36

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[*] 1968 and 1969 cars

[**] Seven-mode, hot start

TABLE 3-21. SUMMARY OF FUEL ECONOMY AND EMISSION TEST RESULTS USING VARIOUS FUEL MODIFICATIONS

Product Name	Product Description	Where Tested	Type of Test	Number of Vehicles	Effect on Fuel Consumption	Effect on Emissions(%)			Model Yr. of Vehicle Tested	Reference
						HC	CO	NO_x		
Bycosin	additive	EPA	1972 CVS	1	no data	-10	-10	-10	1962	3-78
Stargas	additive	EPA	1972 CVS	2	+(1-5%)	+7	+7	+7	1970, 1971	3-79
Auto-mate	additive - reduce NO_x	EPA	dynam. st. state	1	0	0	0	0	1969	3-80
Sta-power	additive - detergent	EPA	7 MHS	1	0	0	0	0	1970	3-81
Val-do, Powerlube	additive - detergent	EPA	1975 CVS	1	0	0	0	0	1962	3-82
Technol G	additive - detergent	EPA	1975 CVS	1	-4%	-6	-4	+12	1962	3-83
Andersen	treatment to remove impurities	CARB	7 MHS	1	no data	0	-8	+25	1964	3-84
Edgar	additive - combustion improver (30 ppm Boron, 50 ppm Mangan)	CARB	7 MHS	1	no data	0	-16	-12	1970	3-85
W-6	additive	CARB	7 MHS	1	no data	+18	-25	-77	1968	3-86
BHA	additive	CARB	7 MHS	1	no data	0	+8	-30	1964	3-87
DZL-lene	fuel stabilizer	CARB	7 MHS	3	no data	0	0	+20	1964, 1969, 1970	3-88
Upgrade	additive - manganese-amine complex	Automotive Research Assoc.	highway 1975 CVS	1 1	4% 0	0 -33	0 -25	0 0	1972 1972	3-92
Exxon HTA	additive - surface conditioner to improve fuel distribution	Exxon	highway dynamometer	4 15	-3% -4%	0 -20	0 0	0 -2	1969 1969	3-89

TABLE 3-21. SUMMARY OF FUEL ECONOMY AND EMISSION TEST RESULTS USING VARIOUS FUEL MODIFICATIONS (Concluded)

Product Name	Product Description	Where Tested	Type of Test	Number of Vehicles	Effect on Fuel Consumption	Effect on Emissions(%) HC	Effect on Emissions(%) CO	Effect on Emissions(%) NO_x	Model Year of Vehicle Tested	Reference
Chevron F-310	additive - detergent	Chevron/ Scott	7 MHS	13	-6%	-55	-36	-	1968, 1969 (all vehicles were permitted to accumulate engine deposits)	3-77
Study	additives - carburetor cleaners and dispersants	CRC/Scott	7 MHS	18	no data	0	0	-	1969	3-75
Study	additives - detergents and dispersants	Bureau of Mines	7 MHS	2	no data	0	0	0	1968, 1969	3-76
Gasoline/Alcohol Mixtures	gasoline and 10% methanol	Lincoln Labs	highway	6	-4%	-	-	-	1969 - 1973	3-95
Gasoline/Alcohol Mixtures	gasoline and 10% methanol	Chevron	highway	6	+3%	-	-	-	1971	3-94
Gasoline/Alcohol/ Water Mixtures (Verab-10)	58% gasoline, 28% isopropyl alcohol, 14% water	Verab Assoc./ CARB	CVS-H CVS-C	3 3	-4% -1%	-20 -10	-75 -60	-50 -20	1970 1964, 1970 (results not applicable to 1973 or later)	3-101
Gasoline/Water **(pre-mixed, stored in fuel tanks)**	80% gasoline, 20% water	Ewbank/ CARB	CVS-H	1	+5%	+70	+200	-45	1971 **poor driveability**	3-102
Gasoline/Water Mixture - fuel injection	85% gasoline, 15% water	Zeilinger	engine dynamom. (equiv. ratio held constant)	-	-10%	-10	0	-15	6-cylinder engine alone	3-105

A detailed study of the effect of the HTA additive on the fuel economy, emissions, and driveability of 1966 through 1971 vehicles was conducted by Exxon (Ref. 3-89). The results of that study, taken from Ref. 3-89, are summarized in Table 3-22. As indicated in Table 3-22, it was found that the fuel economy was improved on the average by 3% to 5% when HTA was added to the fuel. As is usually the case in such studies, there was considerable variation in the effect of the additive on a car-to-car basis, and thus a car fleet of reasonable size and diversity is required to obtain reliable data. The effect of the HTA additive on vehicle emissions is also shown in Table 3-22. In general, it was found that the addition of HTA to the base fuel reduced HC emission by 15% to 20% and had little effect on CO emissions. The HTA additive was found to be more effective in reducing emissions than the detergent additives.

In summary, it was found in the Exxon study that fuel additives could improve the fuel distribution in the induction system of engines and that modest, average improvements in fuel economy (3% to 5%) and HC emissions (15% to 20%) would result.

3.6.2.1.3 Nitrogenous Manganese Additive

A nitrogenous manganese additive for use in distillate oils and gasoline has been patented (Ref. 3-90) by the Rolfe Chemical Company, Stamford, Connecticut. The additive has been used in boiler combustors and diesel engines for several years, primarily for smoke control, and more recently in spark ignition gasoline engines to reduce emissions and improve fuel economy. A division of the Rolfe Chemical Company, The Fuel Improvers, is presently marketing the additive in bulk quantities (barrels) to fleet operators, and it is likely that in the future they will market the additive under the trade name Upgrade in small cans for purchase by individual car owners.

TABLE 3-22. SUMMARY OF TEST RESULTS USING THE HTA GASOLINE ADDITIVE (Ref. 3-89)

Effect of HTA on Fuel Economy
Dynamometer Experiments: Suburban Tape

Fuel	Car	Year	Displacement, cu. in.	% Improvement
Premium	A	1969	440	5.5
	B	1969	390	2.4
	C	1969	429	7.3
	D	1969	400	5.5
	E	1970	350	1.9
	F	1970	440	1.3
	G	1970	429	5.3
	H	1971	455	6.7
	I	1971	429	5.7
				4.6 Average
Regular	J*	1966	283	-0.1
	K*	1967	289	13.9
	L	1970	351	3.7
	M	1970	383	2.1
	N	1970	400	4.3
	O	1971	400	2.0
				4.3 Average

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*No emission control

Effect of HTA on Road Fuel Economy

Car	% Improvement Over Base Control Group	% Improvement Over Base HTA Group
1969 Chrysler	+3.1	+4.6
1969 Chrysler	+0.3	-0.8
1969 Mercury	-3.4	+6.0
1969 Mercury	-0.1	+3.2
4-Car Average	0.0	+3.3

Employee Fleet Emissions Test

Test Procedure: 1968 Federal Test Cycle (Hot Start)

	Regular Fuel		Premium Fuel	
	Base	Additive	Base	Additive
No. of Cars	17	20	12	11
HC (IR) Initial	438	430	386	343
Final	440	365	339	226
% Reduction	-0.5	15.1	12.2	24.1
Confidence Level, %	---	99	99	99

Note: Improvement over base premium fuel was significant at the 90% confidence level.

Emission Results: 1968 Federal Test Cycle (Cold Start)

4-Car Averaged Emissions

	CO, %	HC, ppm	NO, ppm
Dispersant Group			
Base Regular	0.81	178	1313
Base + Dispersant	0.97	153	1261
HTA Group			
Base Regular	0.85	183	1269
Base + HTA	0.85	145	1244
HTA/Dispersant Group			
Base Regular	0.87	183	1366
Base + HTA/Dispersant	1.01	146	1264

State Police Fleet Emissions Test

Test Procedure: 1968 Federal Test Cycle (Hot Start)

	CO, %	HC, ppm
Initial	1.88	265
Final	1.86	199
% Reduction	1.10	25
Confidence Level, %	----	99

This additive is a complex of a manganese salt, amine group, and hydrocarbon molecules. It is added to the gasoline in a concentration of 1:650, resulting in a manganese concentration of at most 3 ppm. The additive is thought to improve the combustion process directly, both by altering the gas-phase kinetics and conditioning the cylinder surfaces with a catalytic coating which aids combustion in the cooler regions near the surface. The active chemicals in both instances are manganese and its oxides. In addition to its effect on combustion, the additive also acts as a detergent. Information/data available concerning the effectiveness of Upgrade include an engine dynamometer study of a four-cylinder engine using treated fuel (Ref. 3-91), a vehicle study involving emission and fuel economy measurements on a chassis dynamometer and highway tests of fuel economy (Ref. 3-92), and fleet tests of the effect of the additive on fuel consumption of buses, taxis, and limousines (Ref. 3-93).

The engine dynamometer and fleet tests indicated quite consistently that Upgrade improved fuel economy in automotive engines by 5% to 10%, and, in general, these data seemed to support the claim that the major effect of the additive was on the gas-phase kinetics. This would be consistent with its earlier use as a smoke suppressant in boilers and diesel engines. Unfortunately, the most recent study of the use of Upgrade in a passenger car (Ref. 3-92) at best only partially confirms the earlier fuel economy results, and in addition casts considerable doubt on why and how it works in spark ignition engines. A summary of the test results in the recent vehicle study is given in Table 3-23. In the tests, a 1972 Chevrolet was operated over about 2000 miles using in turn base fuel, base fuel treated with Upgrade, and finally the base fuel again. Measurements were made every 300 miles on fuel economy, both on the road and on a chassis dynamometer. The data shown in Table 3-23 indicate that the steady-state fuel economy (both on the highway and dynamometer) improved only 3% to 5% using Upgrade after a conditioning period of 300 to 600 miles. The driving cycle fuel economy (1975 CVS-CH) did not seem to be improved at all by the additive. In addition, when the test vehicle was switched back to the base fuel, the steady-state

TABLE 3-23. SUMMARY OF VEHICLE FUEL ECONOMY TESTS USING FUEL TREATED WITH UPGRADE (Ref. 3-92)

		Fuel Economy (mpg)		
Miles(1)	Fuel	Highway Trip	55 mph (chassis dynamometer)	1975 CVS-CH
300	base	14.17	16.9(3)	11.0(3)
600	base	14.45	16.9	11.8
900	treated(2)	14.14	17.7	11.8
1200	treated	14.94	17.9	11.2
1500	treated	14.75	18.0	-
1800	base	15.08	18.7	11.4
2100	base	15.17		
2400	base	14.68		
2700	base	14.46		
3000	base	14.41		

(1) Values correspond to "after" miles indicated traveled; vehicle was a 1972 Chevrolet, 350 CID engine.

(2) Base fuel was Indolene HO; treated fuel contained Upgrade in 1/650 concentration.

(3) Each value is the average of three repeat tests; all fuel use measurements made by weighing.

fuel economy with the base fuel was even better than it was using the additive, and it took about 1000 miles before the fuel economy decayed back to its initial value (that is at 300 miles). This behavior indicated that the major effect of the additive may have involved surface conditioning, which is certainly not consistent with the earlier view that its major effect was on gas-phase kinetics. Much more testing would be required to understand how, when, and why the Upgrade additive works and how much, if any, improvement in fuel economy can be expected in the in-use vehicle population in urban/suburban driving. However, any further testing would require a reasonable size and diverse fleet of passenger cars.

3.6.2.1.4 Summary of Status of Fuel Additives

There have been several extensive studies of the effect of gasoline additives (chemicals used in trace concentrations) on vehicle emissions and fuel economy and numerous tests by EPA and state agencies of products presented for evaluation by individual inventors and entrepreneurs. The results of the studies/tests made to date do not offer much reason to expect that additional additives beyond those found in most major brand gasolines today will result in significant average fuel economy improvements in the vehicle population. Some of the detergent additives tested do improve fuel economy a few percent and reduce HC and CO emissions by 20% to 30% when used for 300 to 500 miles in vehicles which have been permitted to accumulate carburetor and engine system deposits. These same detergents have little effect when used in well-maintained vehicles that have been using high-quality gasolines. A few new trace additives, such as the manganese-amine complex, have been developed which offer the possibility of influencing the combustion process directly by altering the combustion kinetics through either gas-phase or surface catalytic mechanisms. However, the limited vehicle test data available using such additives in spark ignition engines have not shown they improve the fuel economy by more than a few percent at most.

3.6.2.2 Fuel Mixtures

In this discussion, fuel mixtures involving gasoline, alcohols, and water are considered. Selected chemical and physical properties of gasoline and these additives are compared in Table 3-24. The following combinations are discussed separately: (a) gasoline and alcohol; (b) gasoline, alcohol, and water; and (c) gasoline and water.

3.6.2.2.1 Gasoline and Alcohol Mixtures

There have been several recent studies of the use of gasoline/alcohol mixtures as fuel for automobiles (Ref. 3-94 to 3-97). Most of the work involved the use of methanol (Ref. 3-94 to 3-96), but some work has been done using ethanol, propanol, and butanol (Ref. 3-96 and 3-97). The following aspects of the use of gasoline/alcohol mixtures as fuels will be discussed in turn in ensuing paragraphs: (a) fuel economy, (b) vehicle driveability and maintenance, and (c) emissions.

3.6.2.2.1.1 Fuel Economy

Two sets of fuel economy tests on late model cars (1969-1974) have been made using gasoline/alcohol mixtures as the fuel (Ref. 3-94 and 3-95). All of the tests were done using methanol as the alcohol in the mixtures. The results of the two studies are given in Table 3-25 and Figure 3-49. It is clear that these data from the two programs are not mutually consistent in that the Massachusetts Institute of Technology (MIT) Lincoln Labs tests indicate that for nearly all the vehicles tested, the fuel economy (mpg) using a 10% methanol/gasoline mix was better than that using gasoline alone, while the Chevron tests found that for all vehicles tested, the fuel economy using the methanol/gasoline mix was less (3.5% on the average) than using gasoline alone. The average improvement in fuel economy using a 10% methanol/gasoline mix in the MIT tests was 4.5%. Both sets of tests involved on-the-road measurement of fuel usage, and in neither case was the carburetion or timing changed for the different fuels. The reason for the difference in the fuel economy test results using the methanol/gasoline mixtures is not known at present.

TABLE 3-24. PHYSICAL AND CHEMICAL PROPERTIES OF GASOLINE AND VARIOUS FUEL ADDITIVES

Substance	Heating Value (Btu/lb)	Heat of Vapori- zation (Btu/lb)	Vapor Pressure at 100°F (psi)	Stoichio- metric Air Fuel Ratio	Motor Octane Rating	Solubility in Gasoline(1) g/100 g Gasoline	Solubility in Water g/100 g
Gasoline	18,700	154	0.3 - 10	14.8	80 - 90	-	< 0.1 (200 ppm)
Methanol	8,644	502	4.55	6.4	92	10(2) - 100	∞
Ethanol	11,604	396	2.25	9.0	89	∞(3)	∞
Propanol	13,300	295	0.89	10.5	87	∞(3)	∞
Butanol	14,284	254	0.33	11.1	85	∞(3)	10(5) - ∞
Water	-	972	0.95	-	-	< 0.1 (200 ppm)	-

(1) No water present

(2) Depends on temperature and aromatic content of the gasoline

(3) Solubility very sensitive to small amounts of water

(4) Soluble in all proportions

(5) Solubility depends on molecular arrangement

TABLE 3-25. COMMUTING FUEL ECONOMY TESTS - CHEVRON (Ref. 3-94)

1971 Car Make	Car Size	Fuel Economy[1] (mpg) No Methanol[2]	Fuel Economy[1] (mpg) 10% Methanol
A	Full	13.0	12.4
B	Medium	15.0	14.9
B	Full	10.8	10.4
C	Compact	20.4	19.8
C	Medium	15.5	14.6

---

(1) commuter travel

(2) commercial unleaded base gasoline

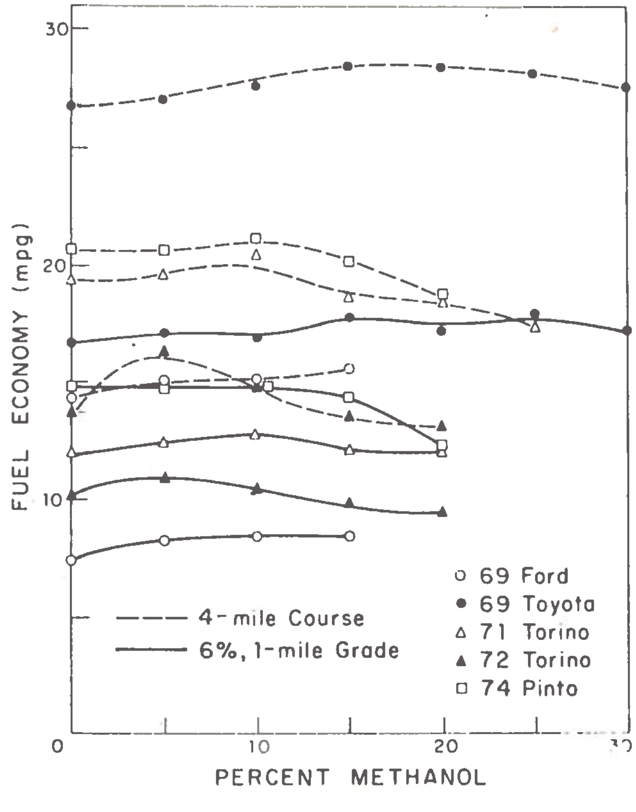

Figure 3-49. MIT/Lincoln Laboratory (Ref. 3-95)

3.6.2.2.1.2 Driveability and Maintenance Problems

Driveability problems (failure to start, stalling, surge, etc.) have been encountered in all the vehicle test programs using methanol/gasoline mixtures as the fuel. The major reason for these problems is that a small amount (1000 ppm) of water in the mixture will cause it to separate into a methanol-rich phase containing the water and a gasoline-rich phase. If the water/methanol phase should reach the carburetor, the engine will stall and likely not restart. Intermittent use of the two phases leads to rough engine operation and poor fuel economy. The methanol/gasoline mixtures become increasingly sensitive to trace amounts of water at low ambient temperatures. The water-sensitivity problem can be mitigated somewhat by adding heavier alcohols (isopropanol and t-butanol in particular) to the mixtures, but relatively high concentrations (5% to 10%) are required to have a significant effect (Ref. 3-94). Unless a suitable water-soluble additive (preferably one used in trace concentrations) can be developed, the practicality of the use of methanol/gasoline mixtures as automotive fuels is highly questionable, even if the results of further fuel economy tests are favorable. It should be noted that the water-sensitivity problem does not arise in using pure methanol as a fuel, because water and methanol are miscible in all proportions and phase separation does not occur.

There are also maintenance-related problems associated with the use of methanol/gasoline mixtures as fuels (Ref. 3-94 and 3-96). These arise from the fact that methanol attacks and/or corrodes various materials customarily used in the fuel system of today's cars. These materials include the lead/tin lining of most fuel tanks, magnesium/aluminum alloys used in some engines, and some elastomers used in filters, gaskets, and plugs. Unless an inhibitor additive can be developed to alleviate these problems, it does not seem feasible to use methanol in fuel blends for the present vehicle population. Similar problems could exist for other alcohols, but they have not been studied as throroughly in this respect.

3.6.2.2.1.3 Emissions

There have been numerous emissions tests of vehicles using pure alcohols and alcohol/gasoline mixtures as fuel (Ref. 3-94, 3-98, and 3-99). Most of the work has been done using methanol as the alcohol. The situation concerning the effect of alcohols on vehicle emissions is reasonably clear, even though there have been many conflicting claims made relative to the advantages of alcohols in reducing emissions. As far as HC and CO emissions are concerned, it is consistently found that if the engines are operated at the same equivalence ratio for alcohol/gasoline blends as for gasoline, there is no significant difference in the emissions found using the different fuels. If, however, the engine is operated at the same A/F, the use of the fuel containing some alcohol results in lower HC and CO emissions than with gasoline, unless the engine is operated beyond the lean limit with the alcohol-containing fuel. In that case, the HC emissions with the alcohols are much higher than with gasoline, and the CO emissions are about the same. The lean limit is leaner for alcohol fuels than for gasoline so that the minimum HC and CO emissions attainable are lower using alcohol fuels. The power output of the engine is also reduced for very lean engine operation with alcohols. The effect of the alcohols on the NO_x emissions is greater than on the HC and CO emissions in that the NO_x emissions are significantly lower (20% to 50%, depending on the volume fraction of alcohol in the fuel) than with gasoline alone, even at the same equivalence ratio. This is particularly true at high rpm and engine loads. The reduced NO_x emissions at the same equivalence ratio are due to the higher heat of vaporization of the alcohols and correspondingly lower peak combustion temperatures, especially for methanol, which was used in most of the emission tests. In addition, operation of the engine at the leaner air-fuel ratios possible with alcohol fuels results in a further significant reduction in the minimum NO_x emissions possible with such fuels.

With regard to engine cold starts, the lower volatility of the alcohols at cold engine temperatures would no doubt require changes in the fuel vaporization systems in order to achieve lower HC and CO emissions on the FTP with the alcohol fuels. In terms of retrofit applications, this difference in fuel volatility could be an important factor. Hence, for late model cars whose carburetors are set lean for low emissions and which have rather elaborate fuel vaporization and choke systems to minimize cold-start emissions, simply adding alcohol to the fuel and further leaning the carburetor to the extent possible without major rework would likely reduce NO_x emissions but with an increase in the HC and CO emissions.

3.6.2.2.1.4 Summary

Available data and information do not support the claim that simply adding an alcohol (in particular, methanol) to gasoline is either a desirable or practical means of improving the fuel economy of in-use vehicles. The limited fuel economy data taken using alcohol/gasoline mixtures in late model cars do not show conclusively that the fuel economy is improved. On the other hand, available information indicates clearly that there are serious driveability problems stemming from the phase separation of the fuel mixtures (water sensitivity) and maintenance problems due to the incompatibility of methanol, and possibly other alcohols, with materials usually found in the fuel systems of today's cars. It is also likely that while the NO_x emissions would be reduced by the use of alcohol in gasoline, the HC and CO emissions could be increased because of the significant difference in the vaporization characteristics of gasoline and alcohol/gasoline mixtures.

3.6.2.2.2 Gasoline/Alcohol/Water Mixtures

The water sensitivity of phase separation in gasoline/alcohol mixtures and the difficulty encountered in preparing stable emulsions of gasoline and water, even with an emulsifying agent, have led to the consideration of gasoline/alcohol/water mixtures for use in late model vehicles. Data and information on the use of such mixtures are available from only two groups. The first group is associated with Goodyear Tire and Rubber, and their work is reported in a patent disclosure (Ref. 3-97). The second group, Verab Associates, is working with Professor Walter Ewbank of the University of

Oklahoma. The Ewbank group has been under contract with the U.S. Postal Service to perform field tests of their fuel modification (Ref. 3-100). In addition, Verab Associates has had their fuel modification evaluated in a series of tests at the California Air Resources Board Laboratory in El Monte, California (Ref. 3-101). Those tests involved both fuel economy and emissions measurements. Various aspects of the use of gasoline/alcohol/water mixtures as automotive fuels are discussed in the following paragraphs.

3.6.2.2.2.1 Mixture Composition

Since it is thought to be desirable to blend a non-trace concentration (5% to 20%) of water with the gasoline and alcohol, the alcohols used by both the Goodyear and Verab groups were isopropyl and t-butyl. These alcohols, which are soluble in both gasoline and water, form stable 3-component solutions having water volume fractions up to at least 5% to 10% without an emulsifying agent. Detailed triangular phase diagrams for the heavy alcohols in solution with water and gasoline do not seem to be available in the literature, so precise information on how much water can be mixed in solution at moderate alcohol fractions (20% to 40%) is not presently available.

Mixture compositions which have been tested as fuels are summarized in Table 3-26. The primary difference between the work of the Goodyear and Verab groups is that the Verab group uses an emulsifying agent and hence larger fractions of water. Otherwise, the approaches taken by the two groups are quite similar. Both groups seem to have concluded that a 60/40 gasoline-alcohol ratio is optimum. The role of the water in the mixture is to alter the fuel combustion process so as to improve thermal efficiency and to reduce emissions, particularly NO_x.

3.6.2.2.2.2 Fuel Economy and Driveability

There has been a series of fuel economy tests conducted by the California Air Resources Board Laboratory using the Verab Associates fuel modification (Ref. 3-101). The modified fuel used was designed as

TABLE 3-26. SUMMARY OF GASOLINE/ALCOHOL/WATER MIXTURE COMPOSITIONS USED AS FUELS (Ref. 3-97 and 3-101)

Alcohol	Emulsifying Agent	Volume Fraction (%) Gasoline	Volume Fraction (%) Alcohol	Volume Fraction (%) Water[1]
GOODYEAR GROUP				
Isopropyl	NO	90	10	0.30
Isopropyl	NO	80	20	1.30
Isopropyl	NO	70	30	3.00
Isopropyl	NO	60	40	5.70
t-butyl	NO	90	10	0.20
t-butyl	NO	80	20	0.70
t-butyl	NO	70	30	1.80
t-butyl	NO	60	40	3.00
VERAB ASSOCIATES				
Isopropyl	YES	50-60	30-40	14
Isopropyl	YES	40-50	40-50	25

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(1) Practice seems to be not to include water in determining gasoline and alcohol volume fractions.

Verab-10. Its composition was approximately 58% Indolene-30 gasoline, 28% isopropyl alcohol, and 14% water. It contained also an unspecified emulsifying agent. The fuel mix was prepared several weeks before the tests, so the mixture was evidently quite stable as no phase separation was observed by the CARB personnel prior to the tests. The model year range of the vehicles tested was quite wide -- 1964 to 1973. Comparison tests were made on each vehicle using gasoline (Indolene-30) and then Verab-10. The vehicle fuel system was purged with the new fuel, and the carburetor set to best lean idle when switching from one fuel to another. Tests were run from hot as well as cold starts.

The results of the fuel economy tests are summarized in Table 3-27. Fuel consumed means gasoline or gasoline plus alcohol, excluding any water in the fuel mixture. On this basis, the heat content (Btu/gal) of the Verab-10 is about 10% less than that of gasoline. The leaning effect of the alcohol and water combined is about 0.20 in equivalence ratio. Based on the limited fuel economy data given in Table 3-27, several tentative conclusions appear to be justified. First, for vehicles not operating at lean air-fuel ratios to attain low emissions, the fuel economy using the Verab-10 fuel was as good as or slightly better than that using gasoline alone, especially for hot-start tests. In these cases, fuel economy was improved about 2% to 3%. Second, for highly controlled vehicles (e.g., 1973 model cars), the use of the Verab-10 fuel without proper carburetor modification results in intermittent lean-limit misfiring. This second conclusion, which is confirmed by the marked increase in HC emissions and poor driveability on the test cycle, suggests that the 5% increase in fuel consumption of the 1973 vehicle may not be representative of a vehicle properly modified to operate on a fuel mix such as Verab-10.

Detailed information concerning the driveability of vehicles using the Verab-10 fuel is not avilable. It is noted, however, in Ref. 3-101, that during the dynamometer fuel economy and emissions tests, the vehicles had a tendency to stall and backfire occasionally when using the Verab-10

TABLE 3-27. SUMMARY OF FUEL ECONOMY TEST RESULTS USING VERAB-10 (Ref. 3-101)

Vehicle	Fuel	Test Procedure	No. of Tests	Fuel Consumption[1]	% Change Using Verab-10
1970-Chevrolet	Gasoline	CVS-H	3	1493 gm/test	
1970 Chevrolet	Verab-10	CVS-H	3	1430 gm/test	-4.2
1970 Chevrolet	Gasoline	CVS-C	3	1703 gm/test	
1970 Chevrolet	Verab-10	CVS-C	3	1719 gm/test	+1.0
1964 Chevrolet	Gasoline	CVS-C	3	.0819 gal/mi	
1964 Chevrolet	Verab-10	CVS-C	3	.0784 gal/mi	-4.2
1973 Plymouth	Gasoline	CVS-C	3	.0887 gal/mi	
1973 Plymouth	Verab-10	CVS-C	3	.0937 gal/mi	+5.5

(1)Average between weighing and carbon balance fuel. This was particularly true of the 1973 Plymouth. That lean-limit misfiring occurred in some cases is not surprising, since the engines operated considerably leaner (0.20 shift in equivalence ratio) using the modified fuel than with gasoline alone.

3.6.2.2.2.3 Emissions

Emissions data for vehicles fueled with gasoline/alcohol/water mixtures are given in Ref. 3-97 and 3-101. The data given in Ref. 3-97 are from a single vehicle tested using various fuel mixtures, while those in Ref. 3-101 are for several different vehicles tested using a single fuel (Verab-10). The emissions data are summarized in Table 3-28. The two sets of data are consistent with each other as well as with similar data taken on vehicles using gasoline/alcohol mixtures as fuel (Ref. 3-96 and 3-99). In fact, the same general comments can be made about the effects of water and alcohol on the emissions of gasoline/alcohol/water-fueled vehicles as were made previously about the effect of alcohol on the emissions from gasoline/alcohol-fueled vehicles. Sufficient data are not presently available to isolate the differences between the effects of alcohol and water on emissions, especially when they are used together.

3.6.2.2.2.4 Summary and Resource Usage Considerations

Only limited information/data are available on the use of gasoline/alcohol/water mixtures as fuel in automotive vehicles. These data indicate mixtures containing 20% to 35% alcohol and 5% to 15% water are near optimum from the fuel economy and emissions points of view, but little is known directly about the effect of varying the water concentration in such mixtures. Dynamometer driving cycle tests have shown that the fuel economy (based on gasoline plus alcohol, but excluding the water) using the gasoline/alcohol/water mixtures is about the same or slightly better than with gasoline alone. Any improvement in fuel economy (mi/gal) using the mixtures would be only a few percent at most. Since the amount of alcohol needed is large (1/5 to 1/3 that of gasoline), the investment in new facilities and/or equipment

TABLE 3-28. SUMMARY OF EMISSIONS TEST RESULTS USING VERAB-10 (Ref. 3-101)

Vehicle	Fuel	Test Procedure	No. of Tests	Emissions (gm/mi)		
				HC	CO	NO_x
1970 Chevrolet	Gasoline	CVS-H	3	2.83	18.0	4.71
1970 Chevrolet	Verab-10	CVS-H	3	2.25	4.0	2.42
1970 Chevrolet	Gasoline	CVS-C	3	3.30	33.2	4.95
1970 Chevrolet	Verab-10	CVS-C	3	3.60	9.60	2.16
1964 Chevrolet	Gasoline	CVS-C	3	6.74	106.5	1.58
1964 Chevrolet	Verab-10	CVS-C	3	4.78	37.8	1.63
1973 Plymouth	Gasoline	CVS-C	3	1.65	13.7	2.93
1973 Plymouth	Verab-10	CVS-C	3	6.71	14.4	1.48

required to implement such a fuel modification would be great. Thus, this is not a likely retrofit approach in the near term.

The driveability of vehicles using mixtures as fuel is likely to be poorer than the same vehicles using gasoline alone. The effect of the fuel modification on driveability can be minimized by proper carburetor adjustments and changes in the vaporization characteristics of the gasoline used in the mixture. Little information is available on the effect of using fuel mixtures containing alcohols and water on the maintenance and durability of vehicles designed to use only gasoline. This latter consideration is very import when considering fuel modification as a retrofit approach.

3.6.2.2.3 Gasoline and Water Mixtures

Some work has been done involving the use of gasoline/water mixtures as a fuel for spark ignition engines. Since gasoline and water are essentially insoluble, special consideration must be given to the manner in which the gasoline and water are brought to the cylinder for combustion. Two approaches have been used. In the first approach, water and gasoline are mixed using an emulsifying agent and vigorous agitation, and the resultant emulsion is stored in the fuel tank of the vehicle. In the second approach, the gasoline and water are stored separately on-board the vehicle, and they are brought together by the carburetion or fuel injection processes. These approaches are discussed separately in the following paragraphs.

3.6.2.2.3.1 Gasoline/Water Emulsions

The Ewbank group, whose work was discussed earlier in connection with gasoline/alcohol/water mixtures, tried initially to use gasoline/water emulsions. Considerable field testing of such a fuel modification was done in Norman, Oklahoma, supported by the U.S. Postal Service. As far as can be determined by contacts with the Postal Service people involved (Ref. 3-100), the attempts to use the gasoline/water emulsion approach were unsuccessful due to the instability of the emulsion. The vehicles operated satisfactorily relatively soon after fueling, but phase separation was encountered when the vehicles remained inoperative for several hours (e.g., when the vehicles sat overnight). This experience apparently led the Ewbank group to pursue the alternative gasoline/alcohol/water mixture approach. Data from only one series of tests using pre-mixed gasoline/water emulsions are available (Ref. 3-102). Tests were conducted by the California Air Resources Board Laboratory in December 1972 on a 1971 VW Squareback with modified fuel injection. As indicated by the data shown in Table 3-29, the tests were not successful, as only the NO_x emissions were reduced by the fuel modification and the fuel consumption was 5% to 13% greater. In addition, the car ran very rough and kept stalling. It is quite possible that even the lowest water fraction (20%) used in the tests was greater than optimum from the fuel economy and driveability points of view.

TABLE 3-29. SUMMARY OF TEST RESULTS USING GASOLINE/WATER EMULSIONS AS FUEL (Ref. 3-102)

Test*	Water in Emulsion (%)**	Emissions (gm/mi) CVS-H HC	CO	NO_x	Gasoline Consumption (gm)
1	0	1.55	22.1	4.6	1077
2	20	2.75	46.8	2.6	1128
3	45	5.15	63.3	1.2	1215

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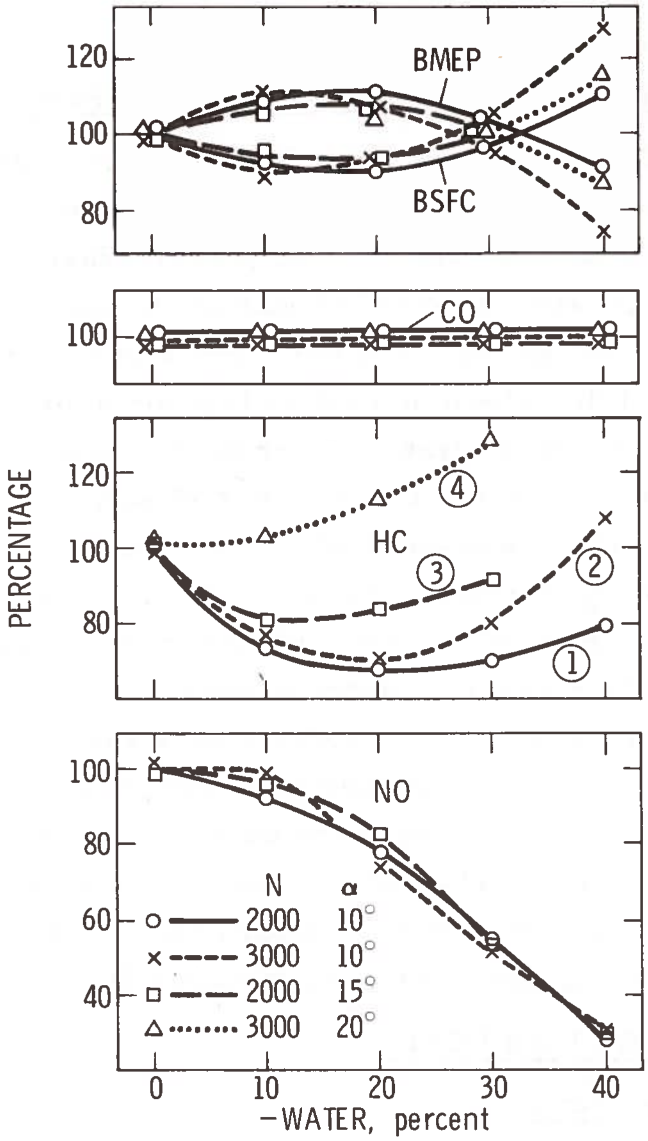
*Vehicle was a 1971 VW Squareback with 1600-cc engine and modified fuel injection.

**Emulsion contained an unspecified emulsifying agent at 2% concentration.

3.6.2.2.3.2 Gasoline/Water Mixing at Carburetion or Fuel Injection

In order to circumvent the problem of phase separation in stored pre-mixed gasoline/water emulsion, it is possible to mix the gasoline and water just prior to or during carburetion or fuel injection. This approach is technically feasible, but, probably due to its complexity, no vehicles employing this modification have been tested to date, either on the road or a dynamometer. The gasoline and water could be stored in separate tanks on-board the vehicle and metered into the intake air through separate carburetor jets or injection nozzles. Another approach would be to mix the water and gasoline prior to injection in an ultrasonic reactor similar to that used/tested for stationary combustion using distillate oils (Ref. 3-103). In the ultrasonic reactor, ultrasonic waves are employed to disperse the water in the gasoline as very small droplets (Ref. 3-104). As discussed under 3.1, the ultrasonic principle has been used recently as the basis for a fuel delivery system to replace the standard carburetor. Regardless of the approach taken to mix the water and gasoline on board the vehicle, new hardware would be required and the cost of retrofit would be substantial.

At least one study has investigated the effect on fuel economy and emissions of injecting a mixture of water and gasoline in an automotive engine (Ref. 3-105). The work was performed on an engine dynamometer using a 6-cylinder engine with fuel injection in front of the inlet valve for each cylinder. The water and gasoline were pre-mixed before injection, using an emulsifying agent (0.3% Necanil C). The water concentration (volumetric percent) was varied systematically up to 40%. The equivalence ratio (ϕ) at each engine operating condition (throttle setting and rpm) was kept constant ($\phi = 1$), as the volume fraction of water in the fuel was varied. The results of the engine tests using gasoline/water mixtures are summarized in Figure 3-50. As far as fuel economy is concerned, it was found that the optimum water concentration is about 15%. At that water concentration, the fuel economy is improved by about 10%, and the HC and NO_x emissions are reduced by up to 30% and 15%, respectively. The CO emissions are essentially unchanged, since the equivalence ratio is maintained constant at all water concentrations. The engine test results shown indicate that a modest fuel economy improvement may be possible using gasoline/water mixtures as fuels, but the magnitude of the improvement for a vehicle in urban/suburban driving cannot be determined from the engine tests. Chassis dynamometer and road tests are required, and no such tests have been made to date.



ABSOLUTE VALUES FOR 0 PERCENT WATER

CURVE	Bmep lbf/in.^{2}	Bsfc, lb/hph	CO, %	HC, ppm	NO, ppm
① ○	54.0	0.56	0.2	570	1470
② ×	32.0	0.76	0.2	400	1040
③ □	76.2	0.49	0.2	510	2180
④ △	86.8	0.48	0.2	320	2300

Figure 3-50. Summary of Gasoline/Water Mixture Injection Tests on a 6-Cylinder Engine (Ref. 3-105)

3.6.2.2.3.3 Summary and Possible Maintenance Problems

Very limited data are available on the effect of using gasoline/water mixtures as automotive fuels. Efforts to use pre-mixed gasoline/water emulsions stored in the fuel tank for long periods (days) have not been successful due to phase separation after only hours of storage. No vehicle tests have been made in which the gasoline and water are stored in separate tanks and are mixed on-board the vehicle immediately prior to or during carburetion or fuel injection. An engine dynamometer study using a 6-cylinder engine and fuel injection has indicated a maximum fuel economy improvement at steady operating conditions of about 10%. The maximum improvement occurred for a water concentration of about 15%. There are no vehicle tests to confirm this possibility of a modest improvement in fuel economy using water injection. The retrofit hardware needed to mix the gasoline and water on-board the vehicle is likely to be both complex and costly.

There are serious questions regarding the effect of the water added to the fuel on the maintenance and durability of the engine and related systems. Rusting and corroding of the internal engine surfaces/parts are certainly possibilities, and a detailed study of the problem is needed before the practicality of using gasoline/water mixtures in vehicles can be determined.

3.7 INLET MANIFOLDS

3.7.1 Introduction

The present design of conventional inlet manifolds for four-stroke spark ignition automotive engines is the result of many years of evolutionary development which began with a simple pipe connection between the carburetor and the inlet ports of the engine head. The progressive development of the high-speed, high-performance automotive engine brought about sophisticated designs of the inlet manifold which had to satisfy a number of requirements, principally those of uniform distribution of the fuel and air mixture to the individual cylinders, proper mixture turbulence, and minimal fuel separation on the walls of the manifold. On the basis of long-term experience, a few general design principles for satisfying these requirements may be postulated:

a. Symmetry of piping (ducting) from carburetor to cylinders (i.e., branches of nearly equal length and cross-section area)

b. Symmetry in time (i.e., evenly spaced suction periods on each barrel of the carburetor)

c. Highest feasible flow velocity of the mixture (i.e., the smallest flow cross-section area of the manifold branches consistent with acceptable pressure loss through the system)

Because of widely varying engine speeds and loads, only a compromise between some of the mutually exclusive requirements can be met, and, because of economic and space limitations, further design compromises are frequently made. As a result, production manifolds, in general, do not entirely satisfy the principal requirements.

Although substantial deviation from an ideal design of the inlet manifold may have a quite detrimental effect on exhaust emissions and on the driving performance of the automobile, generally the effect on fuel economy is relatively insignificant. Conversely, if a special design feature incorporated in the inlet manifold permits a significant change of engine operating parameters (such as reduction of pumping losses by means of a ram-effect and/or, by ultra-lean mixture carburetion, reduction of cycle-to-cycle pressure variation by intensified small-scale turbulence, etc.) then noticeable gains in fuel economy may be realized.

3.7.2 Background

Three areas of inlet manifold development leading to potential fuel economy improvement can be identified:

a. Control of the heat input to the inlet manifold

b. Augmentation of the flow velocity and turbulence in the inlet manifold

c. Harnessing of the gas-dynamical effects resulting from transient flow regime in the inlet manifold

Heat input to the inlet manifold is essential for the formation of the air/fuel mixture (Ref. 3-106). The heat supplied helps to vaporize the separated liquid fuel droplets adhering to the walls of the manifold and thus assists in promoting even fuel distribution to individual engine cylinders. A certain amount of heat is conducted through the manifold walls from the engine and/or from the water jacket. A major amount of heat is transferred at specific inlet manifold locations (hot spots) from bypassed exhaust gases. Intensive heating is of benefit in enabling good engine performance from a cold start; however, it curtails the performance by decreasing volumetric efficiency as soon as normal engine operating conditions are attained. At that time, as little heat as possible should be supplied in order to prevent undue decrease in volumetric efficiency and to lower the tendency of the mixture to detonate. Ideally then, a large amount of heat should be supplied at cold start for a brief period, and no heat at all should be added after the engine reaches normal operating temperature. Fuel savings could be obtained by shortening choke-on operation after a cold start as well as by operating the engine at higher compression ratio or at more advanced ignition timing, which is possible because of the increased octane rating of the air/fuel mixture due to decreased mixture temperature (Ref. 3-107).

One of the fundamental problems in spark ignition engine operation is the cyclic pressure variation in the engine cylinder. The basic causes of this problem are variations both in the start and in the rate of combustion. The presence of these combustion variations means that spark timing and the air-fuel ratio of the combustible mixture cannot be fully optimized. This brings about reduced power and fuel economy and increased exhaust emissions. In Ref. 3-108, it is pointed out that the cyclic pressure variation is caused by mixture velocity variation in the vicinity of the spark plug at the time of ignition. One possible approach to the solution of this problem is to increase the average combustion rate. Turbulent mixture velocity in the combustion chamber has a pronounced effect on the rate at which the charge burns. Inlet manifold design and intake valve configuration are factors which affect the average turbulent mixture velocity within a cylinder.

Evidently there are several ways to generate small-scale turbulence in the engine cylinder. In general, however, the generation of turbulence is penalized by increased flow resistance and therefore by reduced volumetric efficiency of the engine, particularly at wide-open-throttle operation. An approach to circumvent this disadvantage is presented in Ref. 3-109. The conventional inlet manifold of a V-8 automobile engine was replaced by a dual-inlet manifold. A small cross-section manifold was fed from a small bore carburetor and a large cross-section manifold from a conventional two-barrel carburetor. At low engine load, the small cross-section manifold system supplied the charge, and, at higher engine loads, the large cross-section manifold system progressively cut in. Although considerable benefits in exhaust emission reduction were recorded, the driving performance of the automobile equipped with the dual-inlet manifold system was found not satisfactory. In the discussion presented in Ref. 3-109, it is suggested that the disappointing results may have been caused by the "migration problem." The liquid fuel from the discharge end of each branch of the small manifold migrates into the other cylinders via the branches of the large manifold.

The flow of the charge (combustible mixture) through the reciprocating internal combustion engine inlet manifold follows a transient regime. For this reason, the geometry, size, and detail-form of a multi-cylinder engine inlet manifold have a very pronounced effect on the air/fuel mixture formation, on fuel distribution to individual cylinders, and on the resulting flow pattern (turbulence) of the charge inside the individual cylinders. The overall geometry affects the pulsation flow pattern in the manifold and consequently the volumetric efficiency of the engine. These and related aspects are discussed in Refs. 3-106, 3-107, 3-110, and 3-111.

Even if the requirements of equally timed suction events at the carburetor flange of the manifold and of equal length of all the branches communicating to engine inlet ports are satisfied, the gas-dynamical pressure waves in individual branches may interfere with each other and cause reduced volumetric efficiency at certain operating conditions of the engine.

Conversely, the volumetric efficiency can be substantially improved by means of the so-called "ram" inlet manifold. Such manifolds make use of the kinetic energy and inertia effect of the moving mass of aspirated charge to produce a gas-dynamical supercharging effect at the end of the engine intake stroke. The mechanism of this process is similar to that of the scavenging effect produced by tuned exhaust systems.

Many varied designs of ram manifolds have been developed and are marketed for racing and sports car enthusiasts. Furthermore, the ram effect has been applied also to two-stroke engines, mainly to large diesel and gas engines.

Generally, the strongest supercharging effect is obtained when an individual ramming pipe is attached to each inlet port as shown in Figure 3-51. In such cases, the carburetors or fuel-injection units are attached directly to the engine head, one unit per inlet port, and the tuned extension ramming pipes are bolted to each unit. The effect of the length of the ramming pipes on volumetric efficiency as the function of engine speed is presented in Figure 3-52. As indicated, the volumetric efficiency increases with the length of the ramming pipe (note that the peak efficiency is shifted toward the lower engine speed region as the length is increased).

While the most efficient arrangement for making use of gas-dynamical supercharging is to have one carburetor with ramming pipe per inlet port (as shown in Figure 3-52), lesser benefits are also obtainable on more conventional inlet manifold systems. One example is the inlet manifold with long ducting branches, as shown in Figure 3-53.

The corresponding performance characteristic is presented in Figure 3-54 showing a remarkably flat torque curve over the range from 1600 to 3200 rpm.

Generally, the factors which are conducive to high air capacity (high volumetric efficiency) are also conducive to reduced pumping losses and therefore better fuel economy. However in certain cases, an increase in air capacity may be accompanied by increased pumping losses. This can happen if the ramming pipe is made excessively long. In such a case, the pumping

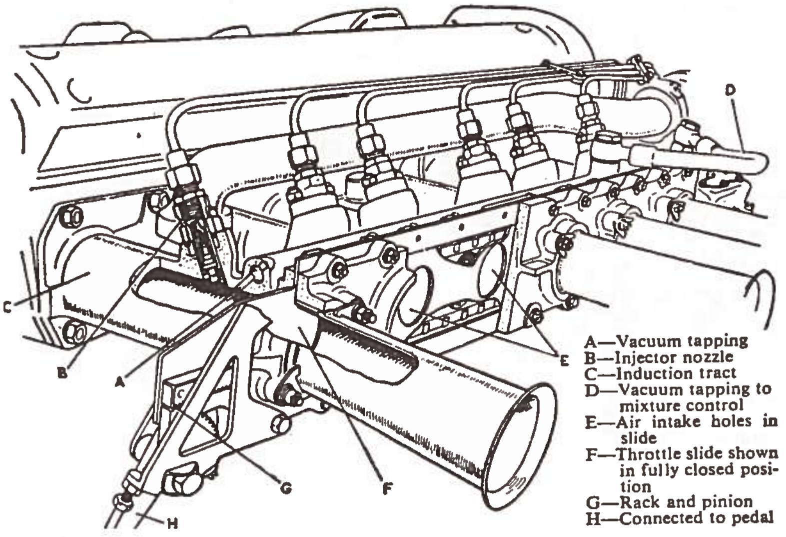


Figure 3-51. Ramming Pipe Air Intake System on a Racing Engine (Ref. 3-106)

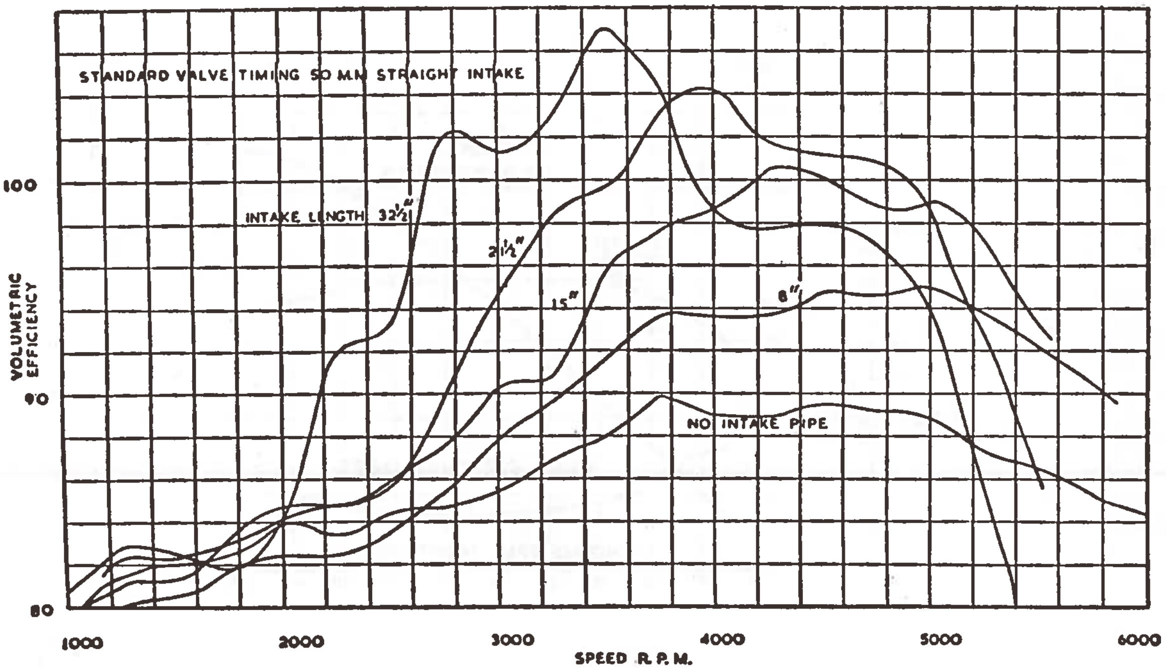


Figure 3-52, Effect of Ramming Pipe Length on Volumetric Efficiency of a Racing Engine (Ref. 3-106)

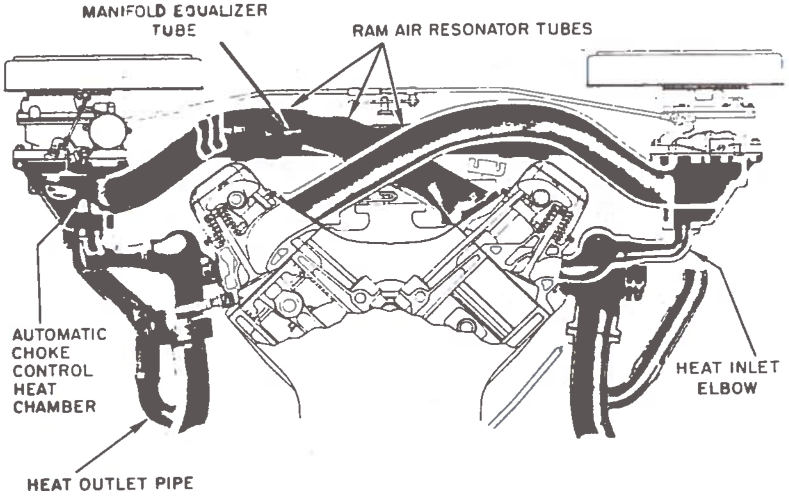


Figure 3-53. Section View of the Long Intake Manifold of a Chrysler Valiant Engine (Ref. 3-106)

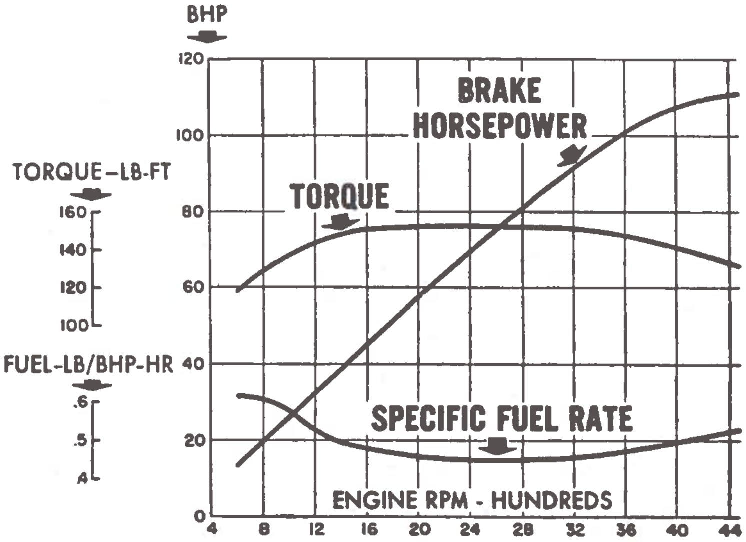


Figure 3-54. Performance Curves of a Chrysler Valiant Engine (Ref. 3-106)

work might be increased due to the inertia of a large volume of air inside the long ramming pipe (Ref. 3-107).

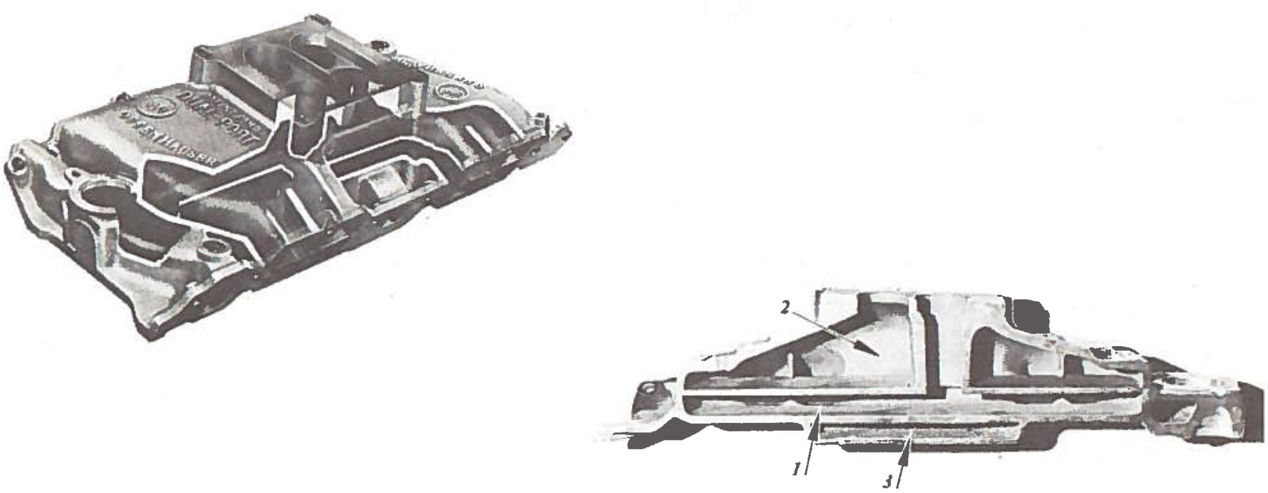
It should be pointed out that the induction ram effect is most pronounced at wide-open-throttle operation and practically nullified at part-throttle engine operation.

On the basis of the present state of the art, as documented by experimental data, it appears that although the ram-inlet manifolds have proven to be effective in increasing the volumetric efficiency of internal combustion spark ignition engines, their capability for reducing the pumping losses and improving the fuel economy of four-stroke engines has not been demonstrated as yet.

3.7.3 Description of Retrofit Systems

3.7.3.1 Offenhauser Dual-Port Manifold

The Offenhauser Corporation in Los Angeles, California, has been manufacturing high-performance inlet manifolds and related equipment since the 1940s. In 1973, a U.S. Patent No. 3,809,032 was granted on the Offenhauser dual-port 360 inlet manifold. Since its introduction on the market, this manifold has been tested and the results published by several car magazines. Power gains, better performance, reduced emission, as well as some improvement in fuel economy were reported. In one case, a recreational vehicle magazine reported as much as 15% improvement in gas mileage on a minimotorhome. In response to the generated interest, the California Air Resources Board tested and evaluated the Offenhauser dual-port manifold (Ref. 3-112). The results are presented in the tables on the following pages. Figure 3-55 shows the cutaway view of the Offenhauser dual-port 360 manifold. The primary vertical passage (in communication with carburetor primary barrels) transfers the air/fuel mixture to the "lower runner" which distributes it to all eight cylinders. Because of a relatively small cross-section area, the flow velocity is high, and therefore a good fuel distribution and response in transient operation are attained. The secondary passage (in communication with carburetor secondary barrels) merges into a relatively



Cutaway view discloses some of the little intricacies of the Dual-Port. Arrow number one is the primary mixture passage. Arrows number two and three are the secondary passage and heat riser passage, respectively. Notice how the secondary passages are isolated from engine valley heat.

Figure 3-55. Cutaway View of the Offenhauser Dual-Port 360 Inlet Manifold (Company Advertisement)

large volume above the "upper runner" which also distributes the mixture to all eight cylinders (so-called 360-degree design). The upper runner is in operation only at high engine loads when the throttle valves in the secondary barrels of the carburetor are open. The flow cross-section area above the upper runner is large, and high volumetric efficiency of the engine at high loads and speeds can therefore be maintained. Only the lower runner is heated by means of a heat-riser crossover passage. The Offenhauser Corporation manufactures a complete line of dual-port 360 manifolds for most of the domestic full-size and compact cars as well as for several imports.

3.7.3.1.1 Fuel Economy

Table 3-30 summarizes the results of the testing and evaluation of the Offenhauser dual-port manifold conducted by the California Air Resources Board. Baseline data were obtained at the beginning (and at the conclusion) of the test program on a California Highway Patrol fleet vehicle

TABLE 3-30. EVALUATION OF THE OFFENHAUSER DUAL-PORT 360 MANIFOLD FOR EMISSION AND FUEL ECONOMY EFFECTS (Ref. 3-112)

CVS-1 COLD START TESTS

Date Tested	Odometer, mi	Emissions, gm/mi			Manifold Used	Fuel, mpg
		HC	CO	NO_x		
2-8-74	30,910	5.20	33.74	2.81	Stock	9.41
2-13-74	30,939	2.20	26.92	2.31	Offenhauser	10.05
3-7-74	35,392	2.31	21.22	2.60	Offenhauser	10.10
3-26-74	38,853	2.34	32.94	3.23	Offenhauser	10.18
4-12-74	41,520	2.33	30.41	3.21	Offenhauser	9.40
4-18-74	41,544	5.34	31.18	2.66	Stock	9.91
	Averages	5.27	32.46	2.74	Stock	9.66
		2.30	27.87	2.84	Offenhauser	9.93
	% Reduction	56%	14%	-4%*		+3%

*Increase in emission

CVS-1 HOT START TESTS

2-8-74**	30,921	3.42	10.87	2.87	Stock	10.57
2-13-74	30,951	1.58	10.84	2.77	Offenhauser	11.61
3-7-74	35,440	1.59	11.79	2.61	Offenhauser	11.41
3-26-74	38,864	1.53	8.16	2.17	Offenhauser	10.72
4-16-74	41,536	1.82	8.39	2.57	Offenhauser	11.31
4-18-74	41,552	4.67	8.71	2.60	Stock	11.16
	Averages	4.05	9.79	2.74	Stock	10.87
		1.63	9.80	2.53	Offenhauser	11.26
	% Reduction	60%	0%	8%		+4%

**Average of 2 tests

with a stock inlet manifold. Subsequently, the dual-port manifold was installed, the vehicle was operated for six weeks, and a total of 10,500 miles was accumulated. The vehicle used for testing was a 1973 Dodge Polara with 440 CID engine, 4-barrel carburetor, and automatic transmission. At approximately 4000-mile intervals, a series of tests consisting of cold-start CVS-1, hot-start CVS-1, and steady-state cruise conditions was performed. The data indicate an average fuel economy gain of 3% after cold start and 4% after hot start with the Offenhauser dual-port manifold.

According to information obtained directly from the manufacturer, still better economy can be obtained if the engine and carburetor are tuned so as to take full advantage of the dual-port manifold characteristic. The tuning specifications can be obtained from the company.

3.7.3.1.2 Emissions

A very considerable reduction of exhaust HC has been consistently recorded with the dual-port manifold, as shown in Table 3-30. This is attributed by the manufacturer to better fuel distribution and a better transient performance characteristics of the manifold. Some improvement in exhaust CO emission was shown in cold-start tests. Only a minor increase of NO_x at cold-start and a slight reduction of NO_x during hot-start tests were recorded. The manufacturer reported that on some cars, good cold-start and cold-engine operation was experienced with complete elimination of the use of the choke. If corroborated, this could lead to further significant reductions of CO and HC emissions.

3.7.3.1.3 Cost and Maintenance

The list price of the Offenhauser dual-port manifolds ranges from $100 to $160 and the estimated cost of installation from $30 to $90. All models are designed to accept the mandatory emission-control devices (EGR). No maintenance is required.

3.7.3.2 Edelbrock Streetmaster Manifold

Edelbrock Equipment Company in El Segundo, California, has been a manufacturer of high-performance inlet manifolds and automotive equipment for over 35 years. The Edelbrock Streetmaster inlet manifold is a development of the "Tarantula-type" intake manifold marketed for years for competition cars and in a more recent version (named "Torker") for street/drag strip use. The principal modification from previous models involves scaling down of the manifold flow cross-section areas to obtain high flow velocity of the charge. Figure 3-56 shows the overall view and the detail of the step-wall reversion dams in the branches. It is essentially a single-plane, large plenum manifold with all branches emerging radially from the central cavity. The major changes from previous models are depicted in a cross-sectional view shown in Figure 3-57. The Streetmaster incorporates the crossover heating passage below the central cavity and a flange with communicating passages for installation of the mandatory EGR system. The carburetor flange accepts four-barrel and two-barrel (with adapter) stock or high-performance carburetors.

The Streetmaster is currently available only for small-block Chevrolet engines (from 1957 to present). However, the Tarantula and Torker models are marketed for most of the domestic large displacement engines.

3.7.3.2.1 Fuel Economy

A fuel economy evaluation of the Streetmaster manifold installed on a 1974 Monte Carlo car equipped with a 400 CID engine is reported in Ref. 3-113. Some tests were run by the Edelbrock Company on a chassis dynamometer (seven-mode cycle) and some by the *Motor Trend* personnel on the street. An 18% fuel economy improvement was recorded on the dynamometer and 16% in street driving. However, the reference cited does not specify if the dynamometer test was a cold or hot start and does not present simultaneous emission data, thus precluding comparison with published EPA fuel economy values for the same model year stock vehicles.

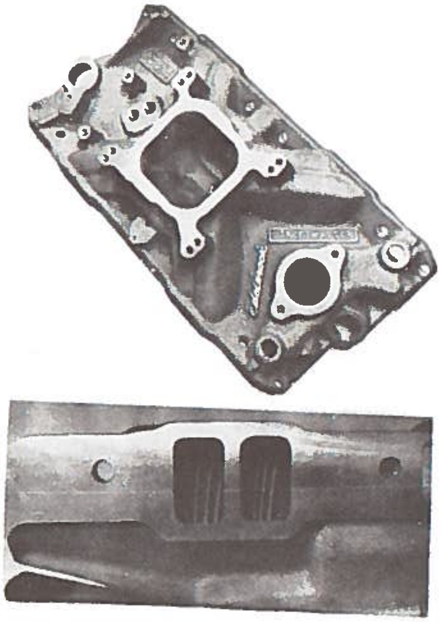
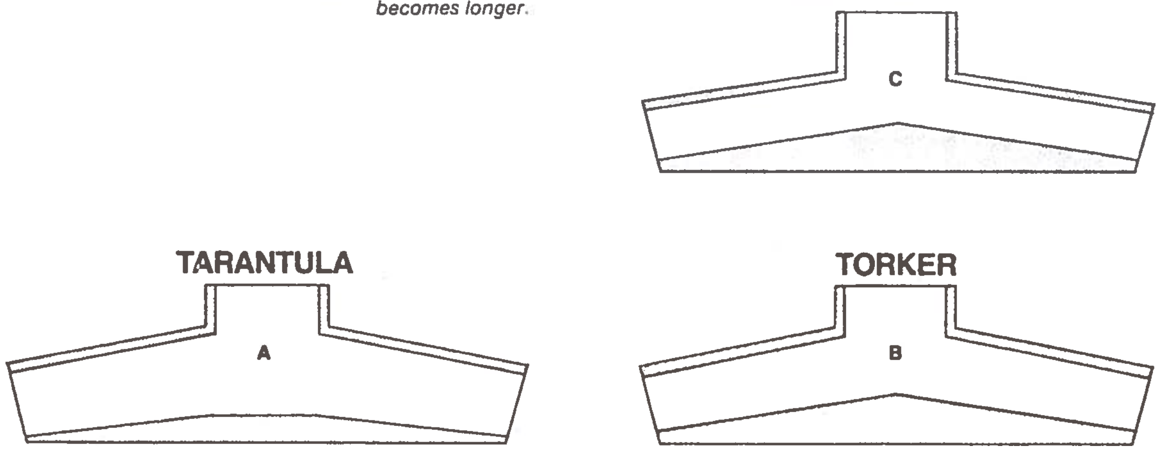


Figure 3-56. View of the Edelbrock Streetmaster Inlet Manifold (Company Advertisement)



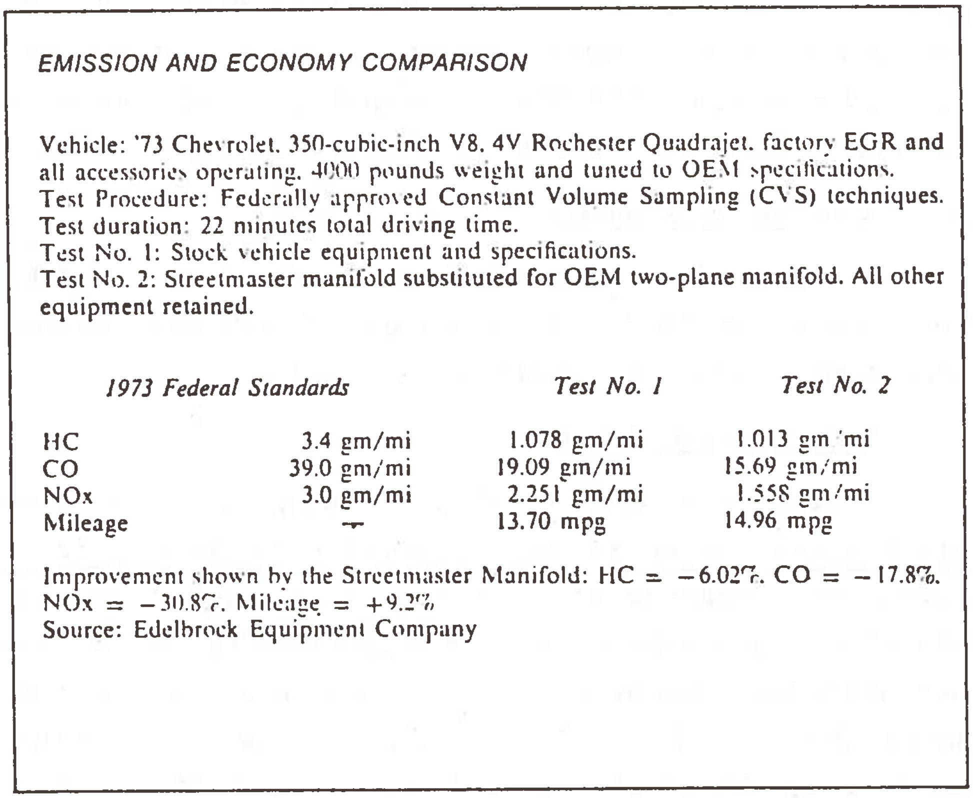
A major change in creating the Torker (B) out of the Tarantula (A) was raising the port and plenum floors. The Streetmaster (C) retains the same floor configuration as the Torker, but has had the port roofs lowered considerably. Note that the carb base column becomes longer.

Figure 3-57. Design Evolution of the Edelbrock Streetmaster Inlet Manifold (Company Advertisement)

Hot Rod magazine published an article on the performance of a 1973 Chevrolet Nova equipped with the Streetmaster manifold (Ref. 3-114) and reprinted data on emissions and fuel economy obtained on this vehicle during a CVS (apparently cold-start) test conducted at the Edelbrock Company. The results as shown in Table 3-31 indicate over 9% fuel economy gain.

In application of the Streetmaster manifold to recreational vehicles, up to 20% improvement in fuel economy has been advertised in several magazines. No test data have been published, however, to support these claims.

TABLE 3-31. EFFECT OF THE EDELBROCK STREETMASTER MANIFOLD ON EMISSION AND FUEL ECONOMY (Ref. 3-114)



EMISSION AND ECONOMY COMPARISON

Vehicle: '73 Chevrolet, 350-cubic-inch V8, 4V Rochester Quadrajet, factory EGR and all accessories operating, 4000 pounds weight and tuned to OEM specifications.
Test Procedure: Federally approved Constant Volume Sampling (CVS) techniques.
Test duration: 22 minutes total driving time.
Test No. 1: Stock vehicle equipment and specifications.
Test No. 2: Streetmaster manifold substituted for OEM two-plane manifold. All other equipment retained.

	1973 Federal Standards	*Test No. 1*	*Test No. 2*
HC	3.4 gm/mi	1.078 gm/mi	1.013 gm/mi
CO	39.0 gm/mi	19.09 gm/mi	15.69 gm/mi
NOx	3.0 gm/mi	2.251 gm/mi	1.558 gm/mi
Mileage	—	13.70 mpg	14.96 mpg

Improvement shown by the Streetmaster Manifold: HC = −6.02%, CO = −17.8%, NOx = −30.8%, Mileage = +9.2%
Source: Edelbrock Equipment Company

3.7.3.2.2 Emissions

The data presented in Table 3-31 indicate the potential for simultaneous improvement of exhaust emissions of HC, CO, and NO_x, and of fuel economy on a 1973 Chevrolet vehicle, when the stock inlet manifold was replaced by an Edelbrock Streetmaster manifold. Of particular interest is the reported significant reduction (30.8%) of specific mass NO_x emission.

The emission test results (hot-start tests) on several other car makes and years presented in Table 3-32 again indicate significant reduction of NO_x emissions. In one case (1972 Ford Mustang), up to 45% reduction in specific mass NO_x emission was reported. Even if the Edelbrock manifold greatly improves the uniformity in fuel distribution to individual cylinders and increases the mixture turbulence, it is not clear how the reported strong reduction of NO_x emission could be accomplished by mere exchange of inlet manifolds. In principle, the effect on exhaust emissions would not be expected to be substantially different from that obtained with the Offenhauser dual-port manifold (officially tested by the Air Resources Board Laboratory) which was developed with the same basic objectives in mind.

3.7.3.2.3 Cost and Maintenance

The Streetmaster manifold retails for about $150.00 plus the installation kit priced at $18.25. Installation costs can be estimated about $90. No maintenance after installation is required.

3.7.3.3 Other Inlet Systems

Several other inlet manifolds or inlet systems have been in development with gains in fuel economy claimed by the developers. Some of these innovations brought to the attention of governmental agencies have been tested by EPA. Brief descriptions and test results have been reported on the Robert Edde Induction System (Ref. 3-115), the Seth Lee Inlet-Exhaust Heat Exchanger (Ref. 3-116), the Roberts Intake Manifold Insert (Ref. 3-117), the Tsurumi Company Manifold Heat Exchanger (Ref. 3-118), and the William Mays Intake Manifold (Ref. 3-119). Table 3-33 presents a summarization of

TABLE 3-32. SUMMARY OF THE EMISSION TESTS OF CARS EQUIPPED WITH THE EDELBROCK STREETMASTER MANIFOLD (COMPANY PUBLICATION)

VEHICLE STANDARDS SUMMARY
(Light-duty Vehicles Under 6000 lbs. g.v.w.)

YEAR	STANDARD	COLD-START TEST	HC (gm/mi)	% Reduction	CO (gm/mi)	% Reduction	NO_x (gm/mi)	% Reduction
1971	Federal/State	7-Mode	1.5		23.0		4.0	
EXHAUST EMISSIONS TESTS*								
1971 Chevrolet Monte Carlo, 402 c.i.d. V8, O.E.M. intake manif., O.E.M. Rochester Quadrajet carb., O.E.M. engine tune-up specs.			1.17		9.28		1.39	
Same as above with substitution of Edelbrock Tarantula TM-20 intake manifold			0.96	18	5.23	43	1.10	20
1971 Chevrolet Monte Carlo, 350 c.i.d. V8, O.E.M. intake manif., O.E.M. Rochester Quadrajet carb., O.E.M. engine tune-up specs.			0.78		3.32		1.47	
Same as above with substitution of Edelbrock Tarantula Torker intake manifold			0.77	1	2.38	28	1.00	32
EXHAUST EMISSIONS TESTS*								
1972 Ford Mustang, 302 c.i.d. V8, O.E.M. intake manif., O.E.M. 2V carb., O.E.M. engine tune-up specs.			4.42		20.41		5.062	
Same as above with substitution of Edelbrock Torker 289 intake manif.			2.63	40	17.76	13	2.748	45
1972 Chevrolet Chevelle, 454 c.i.d. V8, O.E.M. intake manif., O.E.M. 4V Rochester Quadrajet carb., O.E.M. engine tune-up specs.			1.09		10.59		4.688	
Same as above with substitution of Edelbrock Torker-20 intake manif.			1.05	3	7.64	28	3.748	20

YEAR	STANDARD	COLD-START TEST	HC (gm/mi)	% Reduction	CO (gm/mi)	% Reduction	NO_x (gm/mi)	% Reduction
1973	Federal	CVS-I	3.40		39.00		3.00	
EXHAUST EMISSIONS TESTS*								
1973 Chevrolet Impala, 350 c.i.d. V8, O.E.M. intake manif., O.E.M. 4V Rochester Quadrajet carb., O.E.M. engine tune-up specs.			1.078		19.09		2.251	
Same as above with substitution of Edelbrock Torker intake manif.			1.079	0	15.47	19	1.947	13
Same as above with substitution of Edelbrock Streetmaster intake manif.			1.051	2	15.69	18	1.558	31
1973 Chevrolet Impala, 350 c.i.d. V8, O.E.M. intake manif., O.E.M. 4V Rochester Quadrajet carb., O.E.M. engine tune-up specs.			1.26		31.19		2.092	
Same as above with substitution of Edelbrock Torker intake manif.			1.25	0	19.84	36	2.010	4
Same as above with substitution of Edelbrock TM-1 intake manif.			1.09	13	28.49	9	1.989	5

*Based on Hot Cycle Tests

TABLE 3-33. SUMMARY OF SURVEYED INLET MANIFOLDS

Device	Offenhauser Dual-Port 360° Manifold	Edelbrock Streetmaster Manifold	Robert Edde Induction System	Seth Lee Inlet - Exhaust Heat Exchanger	Roberts Manifold with Cone Insert	Tsurumi Co Manifold Heat Exchanger	William Mays Inlet Manifold
Degree of Fuel Economy (Miles Per Gallon) Improvement	4% *	9% - 14% *	18.5 mpg *	negative	negative	N. I.	0%
Retrofit Device or "Kit" Content and Physical Characteristics	see Figure 3-55	see Figure 3-56	manifold with gaps for removal of unvaporized liquid fuel from intake charge	complex induction system employing heat exchanger and air blower	trunkated cone inserted between inlet-manifold and engine head	special manifold heat exchanger plus air bleed system	manifold branches conically tapering towards inlet ports with steps in wall surface
Compatibility with Mass Production	yes	yes	N. I.	N. I.	N. I.	N. I.	N. I.
Potential Availability in Quantity in Near Future	35,000 units per year	50,000 units per year	N. I.	N. I.	N. I.	N. I.	N. I.
Applicable Vehicle or Engine Models (Gasoline and Diesel)	gasoline l. d. vehicles	gasoline l. d. vehicles	gasoline l. d. vehicles	gasoline l. d. vehicles	gasoline l. d. vehicles	gasoline l. d. vehicles	gasoline l. d. vehicles
Attendant Installation Requirements (including Necessary Facilities)	service garage equipment	service garage equipment	N. I.	N. I.	N. I.	N. I.	N. I.
Installation Time Requirement	2 - 6 hours	2 - 6 hours	N. I.	N. I.	N. I.	N. I.	N. I.
Cost to Consumer for Device for Installation	$100 - $160 $ 30 - $ 90.	$135 - $165 $ 30 - $ 90	N. I.	N. I.	N. I.	N. I.	N. I.
Special Maintenance Requirements	none	none	N. I.	N. I.	N. I.	N. I.	N. I.
Effect on HC, CO, and NO_x Emissions (if any)	over 50% HC reduction	6% HC, 18% CO, 30% NO_x reduc.	reduction of CH, CO and NO_x	1.7 gr/mile NO_x *	27% NO_x reduction	no improvement	N. I.
Effect on Vehicle Power and Acceleration Performance (if any)	improved power	improved power	N. I.	negative	negative	N. I.	improved acceleration
Type of Data Available	CVS - test cold start	CVS - test hot start	75 FTP	75 FTP	70 FTP 72	75 FTP	steady state operation
Source and Reliability of the Data Base	ARB and company tests	company tests	EPA	EPA	EPA	EPA	private communication with Prof. V. P. Roan
Theoretical Background	see under 3.7.2	see under 3.7.2	N. I.	N. I.	N. I.	N. I.	N. I.
Remarks	* ARB official test data	* company tests, no official data	* no baseline data	no baseline data			

N. I. = no information

available information pertaining to the surveyed concepts. From all of these, only the Edde Induction System appears to have some potential for fuel economy improvement and for substantial reduction of the exhaust emissions. The results of the evaluation by EPA (Ref. 3-115) are presented in Table 3-34.

The special feature of the Edde manifold is the method by which the unvaporized liquid fuel is removed from the intake charge before it reaches the engine intake ports. It is accomplished by use of a system of gaps (slots) in the bottom of the manifold which can be crossed only by fuel in a vapor state or suspended in the aspirated charge. Any liquid fuel flowing along the bottom of the manifold falls into the gap and is transferred back into a reservoir. The object of this approach is to reduce the cold-start emissions resulting when extra fuel is supplied to ensure that there is enough vaporized fuel for combustion. Evidently the uniformity of fuel distribution to individual cylinders is also improved if only fuel in a vapor state reaches the cylinders. The carburetor can then be set leaner than is practical with conventional manifolds. The system also includes modification to the carburetor accelerator pump which does not discharge fuel under slow throttle movement. The intake air is preheated to improve fuel vaporization. During

TABLE 3-34. EMISSION TEST RESULTS FOR CAR EQUIPPED WITH THE EDDE MANIFOLD (Ref. 3-115)

1975 Federal Test Procedures -all data in grams per mile-			
Test Number	HC	CO	NO_x
18-0225	1.54	5.97	1.86
12-2212	1.63	7.69	2.40
12-2213	1.51	5.23	2.13
Fuel Consumption (carbon balance)			18.5 mpg

the evaluation by EPA, however, it was concluded that this system is too complicated and expensive to be considered as a retrofit system for used cars (Ref. 3-115).

3.7.4 Summary of Inlet Manifolds

Widely advertised claims of substantial fuel economy gains have been made for specially designed (high-performance) inlet manifolds as retrofit devices for automobiles. Table 3-33 presented the summary of surveyed inlet manifolds available in the automotive specialty market or under development. Of the commercially available inlet manifolds, test data from an official testing laboratory were obtained only on the Offenhauser dual-port manifold. These results indicate a fuel economy improvement in the range of 4% and very substantial reduction (60%) of HC emission. However, these gains are based on test evaluation of only one automobile. It is not known what benefits would result by installation of this manifold on other makes and years of automobiles. Also, no test data are available to indicate how much the fuel economy improvement could be augmented by additional retuning of the carburetor and ignition system.

Several cold-start, hot-start, and road tests of the Edelbrock Streetmaster manifold on a few makes and years of automobiles were performed by the Edelbrock Company. The data obtained on a 1973 Chevrolet Nova (CVS test) show a 9% fuel economy improvement with a certain reduction of all exhaust emissions. One road test of a 1974 Monte Carlo retrofitted with a Streetmaster manifold indicated about 16% fuel economy improvement. However, no statement was made about the condition of the engines for the baseline tests and whether adjustment or tuneups of carburetors and ignition systems were made with the installation of the Streetmaster manifold. No test performed by an official or independent laboratory was reported.

In several magazines, substantial fuel economy gains (up to 30%) are advertised for automobile engines retrofitted simultaneously with high-performance inlet manifolds, tuned exhaust systems, and in some instances also with high-performance camshafts. No official test data to substantiate these claims have been published at this writing.

Few special inlet manifolds in the development stage have been tested by the Environmental Protection Agency. The inlet manifold and induction system developed by Robert Edde has been found to substantially improve the exhaust emissions as well as to preserve a good fuel economy. Other induction systems and manifold concepts developed by William Mays, Tsurumi Trading Co., Seth Lee, or by Roberts, which were tested by EPA or another testing laboratory, have shown no significant merits in respect to fuel economy or exhaust emissions.

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