Transcript of Discussion of Various Fuel Injection at SAE 1957

- Thanks to Jim Bartuska
- JGrady 2018

other fuel injection systems, it has these advantages:

1. Elimination of the expense and complication of a high-pressure metering-type pump.
2. Fewer moving parts.
3. No special pump-drive from engine.
4. No critical filtering requirement.
5. No surge or inertia effects as in a pulsating, high-pressure fuel line.
6. No vaporlock.
7. Self-priming.
8. Easier adaptation and assembly line installation.
9. Quieter operation.
10. Low electrical requirements.
11. No ultra-precision machining standards.

When comparing fuel injection against carburetor, the Electrojector system has these advantages:

1. Increased power.
2. Higher torque.
3. Quicker cold starting and warmup.
4. Wider latitude in fuel.
5. More room under hood.
6. Idle cutoff.
7. Ambient air compensation.
8. Altitude compensation.
9. Faster, livelier response to throttle, and better all-around performance.
10. Lower hood line possible.
11. Higher volumetric efficiency—intake manifold can be designed entirely for air.
12. Flow efficiency without compromise for distribution to maintain gas velocity at low speeds.
13. No cold muffler on dual exhaust systems.
14. No need for manifold heat—cooler inlet adds to volumetric efficiency and power.
15. Lower intake temperature allows earlier spark, and higher compression without detonation adding to power.
16. No throttle-valve icing.
17. No cornering or hill-angle effects.

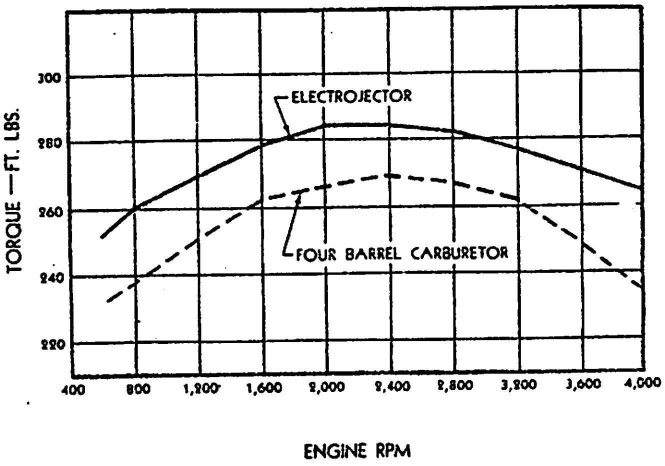

Fig. 16—Typical test results

In conclusion, we are conscious that this is a new concept in fuel metering and poses new and different problems. We and our associates are energetically conducting test programs to add to our knowledge of the system as time and equipment are available.

DISCUSSION

Discusses Pontiac's Fuel Injection System

—J. F. Verkerke
General Motors Corp.

AS you probably know, fuel injection has been introduced by Pontiac for limited 1957 production on our Bonneville Convertible which is being sold to dealers only. This is Pontiac's

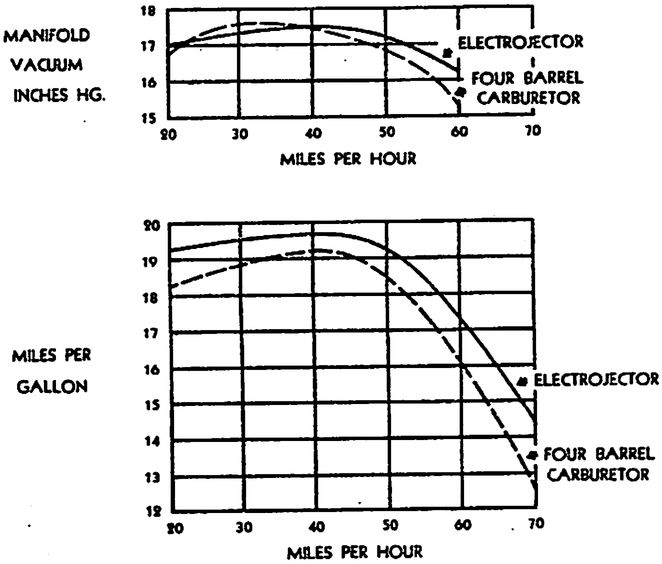

Fig. 17—Road economy tests

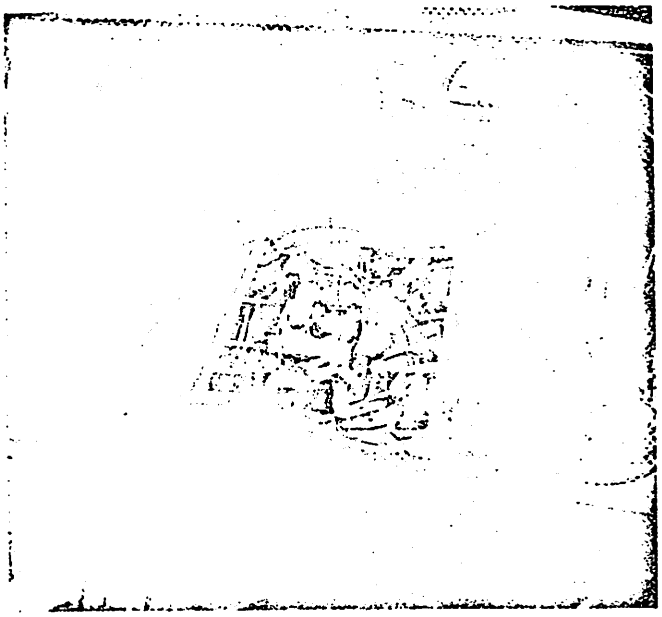

Fig. 18—Electrojector car installation

fuel injection for 1957. Not much more than a name is viewed here so let's look under the hood. Yes, this is the extent of what you'll see of this year's fuel injection for Pontiac. What is actually viewed here is the inlet air duct, the air cleaner, and a shroud which completely encloses the fuel induction assembly. The shroud provides the air inlet box for filtered air to the venturi and nozzles and at the same time provides cooling for the entire system. This feature, in addition to nozzle block and intake manifold insulators, provided the necessary cooling to enable us to still be idling after 30 min at 100 F. A minimum of 30 min at idle at steady state will result in satisfactory city driving at high ambient temperatures. The shroud has also proven itself to be an excellent shield against dust and dirt from collecting on any part of the injection system.

Inside the shroud, Pontiac's basic system is the same as those described in the foregoing papers; however, our development efforts have been directed toward adapting the GM fuel injection system for conventional passenger-car use. Designing and testing intake manifolds of many configurations having various sizes and length ram tubes, led to our released model which provides substantial torque gains above 2000 engine rpm. This design combined with the GM system has resulted in substantial increases in car performance. A gain in acceleration time from 0–60 mph of more than 10% over our conventional 4-barrel carburetor car was achieved.

While our main goal for this year has been to produce a power-plant having all the advantages that fuel injection can offer for superior performance and smoothness under all car driving conditions, fuel economy has not suffered. We have shown level road fuel economy to be about equal to that obtained on our carburetor cars, and during a cross-country trip, the fuel injection car averaged more than 5% better overall economy than a comparison car equipped with a conventional 4-barrel carburetor.

Our performance development has been carried on quite extensively at both the hot and cold extremes of weather conditions. Running in the hot climates has proven our fuel injection system to be resistant to vapor locking tendencies even with high vapor pressure fuels. High altitude running also presented no particular problems. Cold weather development, however, particularly in the range of 0 F has entailed considerably more development.

It can be said that fuel injection offers the engineer a tool with great possibilities for refinement. Our future goal for fuel injection will be to maintain our high standard of performance while simplifying the system with a resultant reduction in cost.

Discusses General Motors and Bendix Fuel Injection Systems

C. G. Nystrom

American Bosch Arma Corp.

THE excellent papers presented by the authors on the subject of gasoline injection is of interest to a great number of people today and of particular interest to the American Bosch Arma Corp. because we, too, have a gasoline injection system of which we are quite proud.

Basic Development

The basic development of the ramjet constant-flow system as presented by Mr. Dolza of GMC, has some very interesting features of note, and both he and his associates should be complimented for their success in this development.

During the development of the American Bosch metered gasoline injection system, we studied various carburetion systems, including conventional carburetors, pressure carburetors, and multinozzle constant-flow arrangements. Among the latter was one basically similar to the system described by Mr. Dolza which was both dynamometer and road tested. In our analysis of all the carburetor and injection systems considered, we concluded that the timed-metered injection system offered the greatest potenial and the most advtantages, not only for the application on existing engines, but in the application to engines of both two and four cycles designed specifically to take full advantage of the gasoline injection.

Messrs. Kehoe and Stoltman, along with their associates should be congratulated on this presentation of the production development of ramjet constant-flow system. It is interesting to note the great detail used in describing the various component parts and the accuracy needed during manufacture, as well as the numerous tests of the component parts of the system, and the final calibration test of the entire system including the intake manifold. The only conclusion I could arrive at was that this type of fuel system has inherent features indicating a high manufacture cost.

Application Development

I will not comment on this phase of the development because we are accessory manufacturers and have to rely on the various engine manufacturers to design the intake manifolds and cylinder heads to be able to take the full advantage of our injection system.

Electrojector

Messrs. Winkler and Sutton, Fuel Systems Engineering Department of the Eclipse Machine Division, Bendix Corp., have made an excellent presentation of this paper on the Electrojector fuel injection system. This system, incidentally, is a timed system as you know, and basically we are in agreement with this idea. The system, which has been described in the authors' paper, has a number of very interesting features. The electronic modulator or "brain box" for the control is a new and attractive approach which is said to have solved the many complex control problems such as optimum air/fuel ratio over the entire speed and load range as well as starting, idling, load, and acceleration enrichment required during warmup and the smooth transition to the requirements of the warm engine. In addition to these requirements, there is the automatic altitude and temperature compensation and the all-important fuel cutoff during deceleration.

The electronic spray valve for metering the fuel is a rather old idea and was developed by Mr. Kennedy of the Atlas Imperial Diesel Engine Co. in 1932. An installation was made on a 6-cyl low-compression spark-ignition oil engine for marine service. This engine was exhibited at the New York Motor Boat Show in January, 1933. In 1934, a smaller oil engine was installed in a truck and was driven from Los Angeles to New York and returned and proved very successful. The description of the Atlas system is published in *Diesel Power*, February, 1933, and *Automotive Industries*, March 4, 1933. The Atlas system lacked proper automatic control. Of course, the knowledge of electronics was very limited 24 years ago, and I don't believe that the transistor was even conceived. It is in this field that Bendix has made the greatest strides, and we should give credit to the author and his associates for the unique adaption of a basically sound injection principle.

Comments on Both Fuel Injection Systems

—M. J. Kittler

Holley Carburetor Co.

BOTH the General Motors paper and the Bendix Aviation paper on their respective fuel injection systems were of great interest. General Motors is to be congratulated on being the first American manufacturer to offer a fuel injection system to the general public on their cars. Bendix Aviation is to be commended for introducing an electronic system as a part of the control mechanism for an automotive fuel injection system. The conception of the electronic control of metering introduces a whole new dimension to the handling of the basic problem of fuel metering control. The future development of electronic controls for fuel metering systems should prove to be very interesting.

As a general comment on both papers, I was rather pleased to note that the claimed improvements with respect to power and economy were held to fairly reasonable limits. It is my opinion that a great deal of early publicity in both the technical press and the general press was highly tinged with optimism, which cannot help but result in disappointment when the actual results are appraised. Gains of the order of 5 to 10% in power and economy appear attainable with a good fuel injection system. Gains in excess of this would arouse some suspicion in my mind at least. It may be well to mention here that it is only fair that fuel injection power data be compared to carburetor data attained with the use of a dual 4-barrel carburetor installation.

I was also pleased to note that fuel/air ratio indicated in the papers, and also distribution variations indicated were in a region not unfamiliar to those acquainted with good carburetion practice. Distribution accuracy between cylinders of 5% total spread, or better, is not easy to obtain, regardless of what kind of a fuel-feed system is used. In the case of fuel/air ratios there is no readily apparent reason why fuel/air ratios required with fuel injection should be appreciably different than those required with carburetors, assuming that a similar range of mixture distribution variations is attained in both installations.

There was a comment relative to speed-density metering versus mass airflow metering. Carburetors operate on the principle of mass airflow metering and the General Motors system, following this same principle, is subject to similar limitations. If the basic venturi size is adequate for maximum airflow at minmum pressure drop, then the metering forces available at low speeds will be exceedingly minute. For this reason we feel that speed-density methods offer better control of metering force than mass airflow methods.

The construction indicated for the fuel nozzles in the General Motors system raises the suspicion that these nozzles may be subject to icing under adverse conditions. These nozzles are carefully insulated to prevent heat absorption, and yet they are, in fact, expansion nozzles and will therefore produce refrigeration. I would like to ask if this condition has been investigated.

The emphasis on the use of rampipes at the intake ports carries overtones of racing engine thinking. As has been so ably pointed out, rampipes are tuned to certain speeds and are only of benefit under wide-open throttle conditions. Whether or not rampipes are used is of no consequence throughout the broad range of ordinary traffic and highway driving and ordinary passenger-car operation. Another obvious disadvantage of rampipes is their very length itself, which adds directly to the overall height of the engine. To be effective, the rampipes must have length, and when they have length they add unwanted dimensions to the engine envelope.

Referring to the Bendix Electrojector system, there are one or two theoretical questions that come to mind.

The first question has to do with the matter of reliability. It has been generally accepted that a hydromechanical mechanism possesses a greater degree of reliability than a parallel electronic mechanism. Undoubtedly great strides have been made in improving the reliability of electronic mechanisms, but I would like to ask what Bendix's experience has been in this area.

The second question has to do with the inertia—mechanical, electrical, and hydraulic—of the fuel and the solenoid valves at high engine speeds. It would appear that inertia effects could become quite pronounced at engine speeds upwards of 4000 rpm.

Since the concept of using an electric brain box for control of fuel metering is so new, it is difficult to envision how easy it would be to change the calibration curves to suit the requirements of different engines. Engine requirements vary widely, and I would be interested in hearing a discussion of the method used to calibrate the "brain box" to meet the engine needs.

It may well be that these two very interesting papers will mark the start of an extended period of evolutionary development of fuel injection systems for motor vehicle engines.

Questions Aspects of Fuel Injection Systems

—E. R. Mason

Chrysler Corp.

THESE comments refer to General Motors fuel injection system. We agree with Mr. Dolza's conclusions that continuous-flow port injection is the most logical and economical system for volume passenger-car production. We also agree that by utilizing a system of this type engine performance is in no way compromised when compared with timed injection of either the port or direct cylinder type.

Before discussing the mass flow system I would like to call attention to the statement that speed-density metering places exacting requirements upon the fuel supply pump. It is stated that the speed-density system requires a pump with constant delivery characteristics. With this we must disagree. The end result of speed-density metering is a controlled fuel delivery nozzle pressure. The speed-density fuel control may be regarded as a pump pressure regulator. So long as the pump is capable of delivering quantities in excess of engine requirements and at pressures in excess of nozzle requirements no other specification need be imposed.

Mass Flow Control

The General Motors arrangement is interesting and obviously is a carefully planned endeavor to develop a practical automotive system. However, the schematic of this system leads to a comment regarding the fundamental approach which was employed. The basic attraction of a mass flow system for automotive use has been that it required no engine-driven components. This feature has been weighed by many against the obvious drawback of mass flow metering. That drawback is lack of adequate control signal at idle and low engine outputs. This performance region is of extreme importance in passenger-car service. In the case of the General Motors arrangement it appears that benefit has not been taken of the most attractive feature of the mass flow system, namely, by incorporation of an engine driven pump.

Fig. 11 shows mixture ratios and their means of attainment in the low output region. It is interesting to note that control of starting, idle, and road load power requirements is not covered by the mass flow system through 50 mph. Throttle ports and differential vacuum signal manipulations provide the basis for fuel metering up to about 220-lb of airflow per hour. A third comment regarding the mass flow system is its well-known tendency to be influenced by pulsating airflow. Can eight individual ram tubes be gathered into a single volume without a resulting pulsation which interferes with desired metering characteristics of the venturi?

Vapor Handling

Throughout, much attention has been given to vapor handling characteristics. This attention we believe is well placed. Vapor handling and control of vapor formation is one of the most difficult and important features of an automotive fuel injection system. I believe many people will agree with me that the most difficult obstacle to development of a satisfactory passenger-car injection system is proper control of vapor. In Mr. Dolza's discussion of air density compensation, he states that proper utilization of fuel vapor bubbles at high temperature is used to cancel adverse air density effects. If this be true, we have met the master; for Mr. Dolza has trained his bubbles better than we have. When studying the vapor handling characteristics of the schematics, I looked in vain for a fuel bowl vent. Fig. 23, however, shows a manifold vacuum vent. The discussion indicates that this vent is restricted to avoid metering disturbances. Inasmuch as it has been indicated that a variation of 0.01 in. of water will affect metering, I do not understand how a controlled vent can accurately maintain bowl pressure anywhere near such limits. If it can, is it possible to handle the large vapor quantities which may result from coasting bypass or normal recirculation at high ambient temperature in so confined a volume as a fuel float bowl? It would seem that during periods of high vapor generation, this vapor augments the normal idle flow and under such conditions can an acceptable idle be maintained.

Vapor lock is mainly a problem of getting fuel from the tank to the fuel bowl. By utilizing an engine-driven diaphragm supply pump it would appear that this system has not solved the generally recognized vapor lock problem.

Nozzles

With regard to the injection nozzle construction and installation on the manifold, considerable importance is placed upon means of using evaporative cooling to control temperature of the fuel delivery line and nozzle as a means of controlling vapor formation. Our experience with low-pressure continuous flow systems has never given any indication that fuel-line temperature was of any importance. We have found that fuel temperature and vapor formation must be meticulously controlled until the metered fuel is delivered to the nozzle line. In the case of this system we wonder if an adverse feature has not been incorporated. It would appear that the refrigeration effect would be highly detrimental to engine operation under atmospheric conditions conducive to ice formation in conventional carburetors.

We wonder if the cold start, warmup, and hot-cranking fuel control has been found to be satisfactory. Our experience indicates that the hot-cranking control and the cold start and warmup device must be interrelated to cover all temperature requirements. Normal hot cranking requires a fuel flow of about 10 lb per hr. Cold cranking may require up to 35 lb per hr. To cover this range of fuel flow with temperature we believe the two devices must act together. In connection with this subject, we wonder if an electrically heated thermal warmup unit can ever be related to any significant engine temperature during either warmup or cooldown. We might also question whether elevation of the cruise fuel/air ratio to power mixture is sufficient to cover warmup requirements.

A last comment on operation of the system would be to question the conclusion that no accelerator pump is necessary. We have found that when the leanest possible road load mixtures have been reached, enrichment is required for solid engine operation during transient accelerating conditions.

Authors' Closure To Discussion

MR. KITTLER has pointed to the fact that gains in power and economy are shown only in the order of 5 to 10%. Perhaps we have been too humble in this respect. Most of the improvements shown are on a steady-state basis with carburetor heat blocked off, while actually we find our largest gains on a transient basis. Gains on the order of 15% are not uncommon for both power and economy. Mr. Kittler further suggests that we make all fuel injection comparisons to the dual, 4-barrel carburetor arrangement. This we would do happily because here is where fuel injection really shines. Our fuel injection system not only shows performance gains in the high-speed range but far surpasses the dual, 4-barrel carburetors in performance at low speeds from the standpoints of power, smoothness, and economy.

Mr. Kittler's remarks concerning mass flow metering limitations are correct as applied to carburetors where it is necessary to use the venturi depression directly as the pressure drop to obtain fuel flow. However, in our fuel injection system the venturi depression is accurately multiplied mechanically to obtain a much greater fuel pressure range. We have found mass flow metering to be the most satisfactory system.

Nozzle icing is not as serious a problem as it first appears to be. The refrigeration from the fuel, fortunately, is very effective at high ambient and fuel temperatures and is very small at low temperatures since it is directly related to the vapor pressure of the fuel. Our nozzle is designed to produce about 10-deg cooling at high temperatures and the small amount of refrigeration at 30 to 40 F ambient causes only a small amount of ice under certain conditions. This ice consists of a thin coating in the large air holes and causes a slight amount of fuel enrichment during warmup but disappears as the underhood temperature increases.

Regarding Mr. Kittler's remarks on rampipes, they are very effective in the 40- to 65-mph range of driving especially with automatic transmissions that shift down and permit engine speeds in the peak ram range.

Mr. Nystrom reports that timed injection offers the most advantages on both 2- and 4-cycle engines. We have found that continuous injection can be made for less cost without sacrifice of power and economy. It is true that timed injection will be best for 2-cycle engines, but we believe that the 4-cycle engines should not be forced to use timed injection and suffer cost-wise because of the 2-cycle engines.

Mr. Nystrom raises the question of nozzle clogging. Our experience during development is that dirt can be removed before assembly and the system will stay clean thereafter.

We are happy to learn that Mr. Mason has come to the same conclusions as we regarding types of injection: that continuous-flow port injection is the most economical system with no sacrifice in engine performance.

Our statement regarding the speed-density metering fuel pump was that it "usually requires a supply of fuel in equal amounts per cycle." We realize that there are some exceptions. For example, the engine speed can be sensed electrically, in which case the pump need not be uniform. Perhaps Mr. Mason is referring to a density metering system with no speed sensor.

It is possible with the GM fuel injection system to have the pump driven separately from the engine. However, we believe the direct engine drive is the lowest in cost and the most reliable.

In our mass flow metering system, we use *manifold vacuum* bleeds to obtain the enrichment required at idle and off-idle. Fig. 11 is an artist's attempt to illustrate the method rather than give exact data. Since the scales do not start at zero, the effect at first appearance seems larger than actually shown; for example at idle, where the bleeds make the largest signal modifications, the effect shown is less than 20%. Actually during our experimental work, we have had some units which required no idle bleed and some required no off-idle bleed.

We have found no disturbance to metering caused by the rampipe pulsations. In fact, we had one experimental installation with only four cylinders and a much smaller plenum volume between the air meter and rampipes, and metering was satisfactory at all engine speeds.

The control diaphragm in the GM fuel injection system is placed between two chambers: the upper chamber is subjected to the metering depression signal, and lower chamber is vented to the static pressure at the venturi inlet. In this manner, the diaphragm is affected by metering signal only and is not disturbed by vapor pressure or manifold vacuum in the float chamber. The lower diaphragm chamber is formed by using a very small hole around the diaphragm link and a large vent to the venturi inlet.

The fuel vapors are then vented from the float chamber to the manifold. Using "educated bubbles," we can alter the effect of the venturi signal so as to lean the mixture at high temperatures.

We have found that most of the vapor bubbles are formed when the fuel is admitted through the float valve; that is, when the pressure is reduced from about 6 psi to atmospheric pressure. During coasting, when the fuel is shut off and no new fuel admitted, there is very little vapor formation.

On hot-idle tests the GM fuel injection system has continued to idle indefinitely where otherwise identical carbureted cars have boiled and were stopped. In these tests, it was interesting ot note that carbureted cars boiled much more readily than fuel injected cars indicating lower heat transfer to the cooling system. As a result, we have found vapor lock much less severe with fuel injection even though we use the same diaphragm pump.

Engines equipped with GM fuel injection system have been found to be much less sensitive to flooding during cranking than with carburetors. The hot and cold starting methods described have been found to be satisfactory on a great number of such tests.

The warmup thermostat is primarily heated electrically by a heating coil energized through the generator armature. At idle when the engine warmup is slow the generator voltage is low, and there is less heat supplied to the thermostat. Also because of its location, the thermostat is somewhat sensitive to ambient air temperaure and engine temperature. This system has proved satisfactory on hundreds of warmup tests.

For warmup enrichment, we have found the air/fuel ratio obtained at the power mixture stop to be sufficient for baseline temperatures as low as −10 F. At lower temperature, a few seconds engine warmup may be required before complete flexibility of the engine can be attained, and this should not be objectionable for the sake of engine wear.

Concerning Mr. Mason's skepticism about our omission of the accelerator pump, we would like to comment that we do not set the control for "the leanest possible road load mixtures." We set our economy stop for the mixture which requires the least amount of fuel for road load. This best economy mixture is considerably richer than the leanest possible mixture at which the engine will run. At this best economy mixture and with the proper attention to details as explained in the paper, we do not need the accelerator pump.

Mr. Kittler has questioned the reliability of electronics. We have had no operational failures during our tests. We have full confidence in electronic components. Also, Mr. Kittler questioned the inertia effects on fuel lines. We have had some trouble. and this was our basic reason for changing to the common rail system.