Comparative Performance of Two Postal Service Vehicles Operated on Gasoline, Compressed Natural Gas, and Propane

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The operational and exhaust emission characteristics of a ½-ton and a 1-ton truck run on three different fuels—gasoline, compressed natural gas (CNG) and liquefied petroleum gas or propane (LPG) were measured. The vehicles were put into an environmental chamber so that the rear wheels rested on a chassis dynamometer. In the series of tests, ambient temperature was controlled at various levels between 0 and 110 F and a range of spark advance settings and air-fuel ratios were used on the engines. The vehicles were run at various dynamometer loads and simulated speeds ranging from idling to 50 mph. HC, CO, and NO_x emissions were measured and the results showed to what extent the various pollutants could be reduced by using the alternate fuels (CNG or LPG).

Contributed by the Heat Transfer Division of The American Society of Mechanical Engineers for presentation at the Winter Annual Meeting, New York, N. Y., November 17-22, 1974. Manuscript received at ASME Headquarters August 9, 1974.

Copies will be available until September 1, 1975.

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ABSTRACT

The operational and exhaust emission characteristics of a 1/2 ton and a 1 ton truck run on three different fuels - gasoline, compressed natural gas (CNG) and liquified petroleum gas or propane (LPG) were measured. The vehicles were put into an environmental chamber so that the rear wheels rested on a chassis dynamometer. In the series of tests, ambient temperature was controlled at various levels between 0°F and 110°F and a range of spark advance settings and air-fuel ratios were used on the engines. The vehicles were run at various dynamometer loads and simulated speeds ranging from idling to 50 miles per hour. HC, CO, and NO_x emissions were measured and the results showed to what extent the various pollutants could be reduced by using the alternate fuels (CNG or LPG).

INTRODUCTION

There are many engine modifications being proposed to reduce the primary pollutants of the internal combustion engine. These include exhaust gas recirculation to alter the air-fuel ratio and reduce peak cycle temperature and the use of secondary combustion processes (thermal reactors). In addition, the use of an entirely different fuel seems feasible for some applications. One such fuel is hydrogen and recent experiments at Oklahoma State University and the University of Miami have been very encouraging. However, hydrogen as a fuel has to be considered only in terms of a long term solution due to problems yet to be solved involving storage, safety, and production.

Gaseous fuels that have potential for immediate use (barring problems associated with supply) are compressed natural gas (CNG) and liquid petroleum gas (LPG), in particular, propane. There has been considerable experience in the last several years in converting conventional vehicles to burn these gaseous fuels and with their use, significant reductions in hydrocarbons and carbon monoxide have been noted along with some reduction in nitrogen oxides. The problems of storage and carburetion have been satisfactorily solved for certain applications so that the total cost of vehicle conversion is about $300.

The pollutant reductions occur as a result of cleaner burning in the engine. With gasoline, the fuel must first be vaporized and then mixed with the correct amount of air. In gaseous fuel systems, the carbuetor only needs to mix in the proper amount of air. This makes the carburetor much simpler, more accurate, and mixing more thorough with minimal cylinder variations.

As with any new system, there are some disadvantages. Today's vehicles must be converted in order to burn gaseous fuels and the fuels, especially natural gas, are not readily available in service stations. Therefore special provisions must be made to obtain and store the fuel.

The Federal Government operates between 300,000 and 400,000 vehicles, often in "fleet" quantities with their own fuel storage system, thus making them an excellent candidate for using gaseous fuels. Consequently, the General Services Administration launched in October of 1969, the Federal Government's first fleet of CNG powered test vehicles. At that time twelve vehicles in the Los Angeles area were converted to a dual-fuel system (with the ability to burn either gasoline or natural gas). Today approximately 1500 GSA vehicles operate with such a system. In addition, the Postal Service has operated a fleet of approximately 50 vehicles in the same manner.

The purpose of this paper is to describe laboratory tests on two Postal Service vehicles, a 1/2 ton truck and a 1 ton truck, that were conducted to determine performance characteristics when operated over an ambient temperature range of 0°F to 110°F. The tests consisted of determining the emission and mechanical performance characteristics of the vehicles when operated at various simulated loads and speeds from idling to 50 miles per hour. Gasoline, compressed natural gas and propane were used as the fuel. Engine settings (air-fuel ratio and spark advance) were varied to observe their effect on performance and pollution. It was intended that these results would be useful in determining the optimum settings for various climatic conditions.

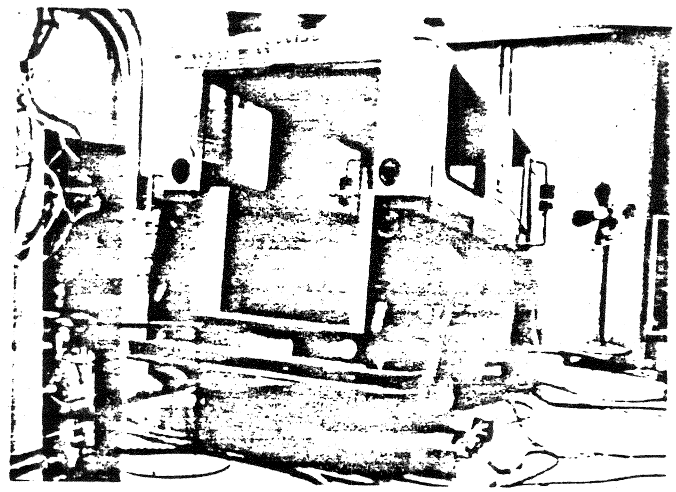

FIGURE 1 1/2 TON TRUCK INSIDE THE ENVIRONMENTAL CHAMBER

DESCRIPTION OF VEHICLES AND FUEL SYSTEMS

The 1/2 ton truck is shown in Figure 1 as it was tested in an NBS environmental chamber. This truck was powered by a 232 cubic inch, 6-cylinder engine. For the first series of tests, the truck was equipped with a natural gas conversion kit so that the vehicle could be run on both gasoline and compressed natural gas. The system used two stages of pressure regulation. A solenoid valve prevented fuel from entering the low pressure regulator when the engine was not operating. The heart of the system was the gas-air mixer which replaced the normal air cleaner on top of the carburetor and made possible use of either natural gas or gasoline interchangeably. The air-mixer, second stage regulator and associated equipment can be seen in Figure 2 installed on the vehicle.

This dual-fuel system was then replaced with the necessary equipment so that a series of tests could be run using both gasoline and propane as the fuels. Propane was run from cylinders typically used with campers and small house trailers through a vaporizer and regulator into the air cleaner shown in Figure 3.

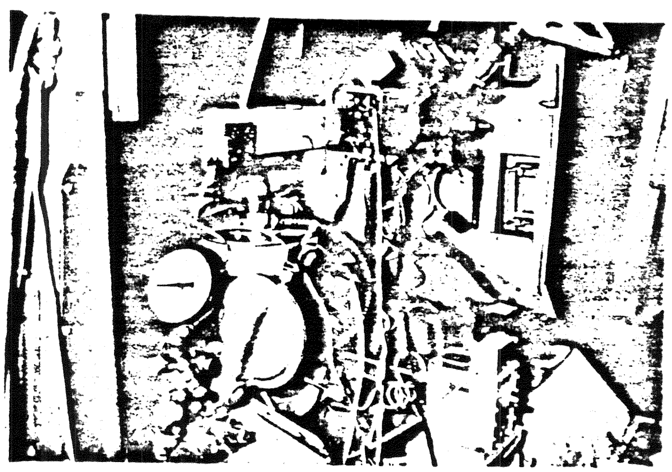

FIGURE 2 AIR-MIXER AND ASSOCIATED NATURAL GAS FUEL SYSTEM FOR THE 1/2 TON TRUCK

FIGURE 3 CARBURETOR ADJUSTMENT FOR PROPANE TESTS

There was one basic difference in these two systems that should be noted. The regulator-vaporizer controlled the downstream pressure at a constant preset level for both systems, however, for the propane dual-fuel system there was a restrictor in the gas line between the regulator and air cleaner (actually an integral part of the inlet port to the air cleaner). The gas flow adjustment for the CNG system was made by adjusting the gas pressure at the regulator. For the propane system, it was made by changing the position of the restrictor. Although, it would appear to make no difference whether the gas flow is adjusted by changing the driving force (pressure) or by changing the flow resistance, there was a substantial difference in the way the gas flow occurred in the two systems as the vehicle speed and load changed. This will be discussed more fully later in the paper.

The 1 ton truck was equipped with a 225 cubic inch, 6-cylinder engine. The particular dual fuel system (CNG and gasoline) installed on this vehicle was somewhat different in the carburetion and the way in which the flow of gas to the carburetor was controlled. Where the other systems used an air-mixer, this system fed the gas at a constant pressure into the throat of a venturi insert that was mounted on top of the gasoline carburetor (Figure 4). The gas flow to the insert could be adjusted by changing the position of a power valve which was nothing more than a screw valve or restrictor that provided additional resistance to the flow (just before entering the carburetor). Therefore as one would expect, the system performed similarily to the propane dual-fuel system used on the 1/2 ton truck.

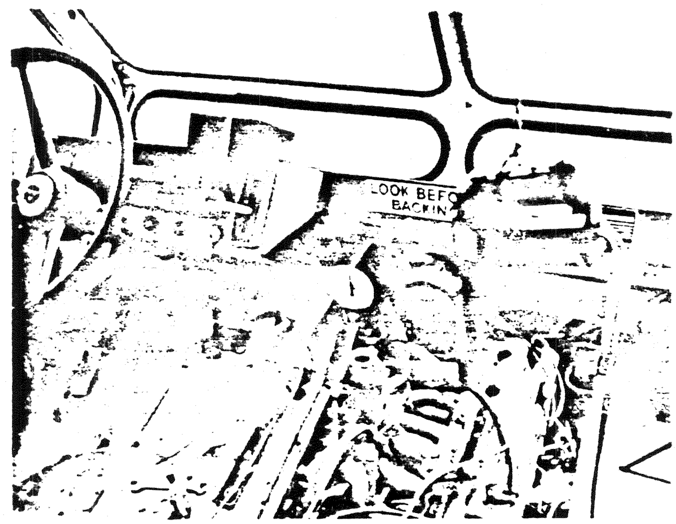

FIGURE 4 SIX-CYLINDER ENGINE EQUIPPED WITH VENTURI INSERT NATURAL GAS FUEL SYSTEM

TEST APPARATUS AND PROCEDURE

In order to determine the mechanical performance and emission characteristics the vehicles were tested in an environmental chamber where the temperature could be controlled over the range -50°F to 150°F. The vehicles were mounted so that the rear wheels rested in a chassis dynamometer. One of the rollers was connected directly to a tachometer generator for determining the vehicle speed while the other roller was attached directly to a power absorption unit which provided the load for the truck.

Once the vehicle was running at a specified speed and load at a particular chamber temperature, a series of measurements were made to determine the pollution and mechanical performance characteristics of the vehicle. These measurements are indicated in the schematic of Figure 5. Potentiometer readings were taken of the copper-constantan thermocouples used to determine ambient air temperature in front of the radiator, water coolant temperature, inlet air temperature at the carburetor, and the chromel-alumel thermocouple used in the exhaust pipe before the muffler.

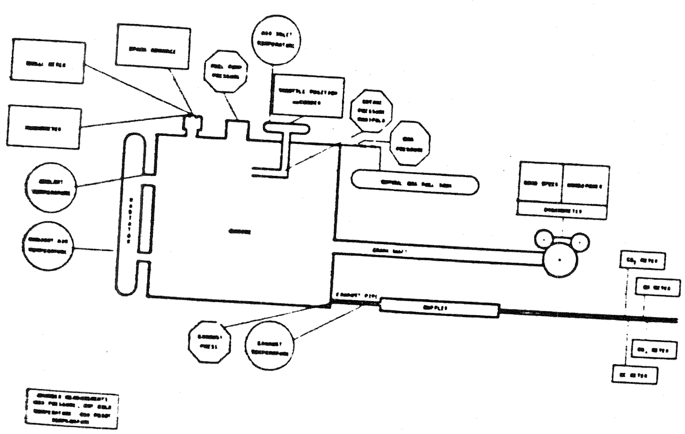

FIGURE 5 VEHICLE AND ENVIRONMENTAL PARAMETERS MEASURED DURING A VEHICLE TEST

The fuel pump pressure (for gasoline 'peration) was measured using a conven- ional bourdon-tube pressure gauge mounted n the cab of the trucks. A similar gauge indicating inches of Hg. vacuum) was used o measure the intake manifold pressure. ne manifold was tapped and connected to the gauge in the adjoining instrument room using 1/8 inch copper tubing. In a similar manner, the gas pressure following the second stage gas regulator and the exhaust pressure were measured by taps connected to water manometers in the instrument room. Additional pressures at several places in the gas flow system were monitored by bourdon-tube gauges. The purpose of these latter measurements were simply to insure proper operation of the systems and a sufficient gas supply in the tanks.

A tach-dwell tester was used for setting the dwell angle and measuring engine speed. A conventional timing light connected with the spark plug of the first cylinder was used for setting the spark advance. A throttle position recorder was used because the throttle position was controlled from the adjoining instrument room. This recorder consisted of a small electric slave motor and shaft attached to the throttle linkage at the engine and a master motor in the adjacent instrument room. The position of the master motor indicated degree of throttle opening between 0 and 100% (full throttle) within 1% intervals, thus allowing for steady control and consistant repeatability. A small servomotor system was used to adjust the distributor for setting the spark advance on the 1/2 ton truck. The system was calibrated with the timing light and checked frequently. It was not mechanically convenient to install this latter system in the 1 ton vehicle so the distributor was adjusted manually.

CO, HC, and NO_x emission measurements were made. In addition, CO_2 was measured so that the air-fuel ratio could be determined for any particular test by exhaust gas analysis. The exhaust gas was sampled by withdrawing part of the mixture from the exhaust pipe bubbling it through glass water traps to condense the excess water vapor and then passing it to the various analyzers. All analyzers were calibrated by periodically measuring the pollutant content of containers of standard commercial span gas.[1]

[1] The absolute accuracy of all the data can only be as good as the commercial instruments' calibration since the accuracy of commercial span gas is questionable.

An Olson-Horiba[2] Model GSM-300 was used to measure the content of CO and HC and a Lira[2] Model 300 to measure the CO_2 content. A Dynasciences[2] Air Pollution Monitor Model NX-130 was used to determine the amount of nitric oxides in the exhaust gas. The CO and HC meters operated on an infrared absorption principle while the NO_x meter was based on an electro-oxidation principle.

The number of independent variables involved coupled with the unique way in which the vehicles and their systems performed required modifications in the procedures as the project progressed. An attempt will be made here to describe the testing steps common to all tests while the deviations in testing procedure will be noted in discussing the tests results.

In general two kinds of tests were conducted: spark advance tests and air-fuel ratio tests. In all cases, the chamber temperature was adjusted to and controlled at a prescribed level using the control system and sensors permanently housed in the environmental chamber facility. All chamber air temperature data used were measured in front of the vehicle at the radiator. While the chamber temperature was being brought to the correct level, all instrumentation systems were powered. The soaking time was in all cases from a minimum of several hours to overnight. The internal temperature of the engine was noted by a thermocouple in the crankcase. Once a test run was begun, no data were recorded until it was assured that steady-state conditions had been reached. This was determined by observing a steady-state condition in vehicle coolant temperature or pollutant readings for at least five minutes.

Spark advance tests were conducted on the trucks running on natural gas, propane and gasoline. Since the gasoline carburetor jets were fixed, no prior adjustments were made in the fuel system. For the natural gas and propane tests, specific settings were made in the gas flow system. For the 1/2 ton truck, it was the second-stage regulator pressure when using CNG and the position of the restrictor when using LPG. For the 1 ton truck it was the position of the power valve or restrictor. In addition, on the 1/2 ton truck using CNG, an adjustment at the air-mixer (on a screw-valve called the tweeker) had to be made. This screw-type adjustment had an effect on the resulting air-fuel ratio (as did the second stage regulator pressure). The procedure that was followed in all tests (spark advance as well as air-fuel ratio tests) was to adjust this tweeker to as lean a mixture as possible (determined by the smallest reading on the CO meter) and still obtain a good idle (indicated by smooth running with no missing).

After these basic gas flow adjustments were made, the spark advance tests were conducted by starting the vehicle, adjusting the idling to 550 rpm and setting the distributor so that cylinder firing occurred at top dead center. The throttle was moved until a specific simulated road speed was obtained. The dynamometer was then adjusted to a predetermined load, and the throttle readjusted to maintain the required road speed. After all indicators had stabilized, the various readings indicated in Figure 5 were recorded.

The distributor was then adjusted so that the firing was advanced three degrees and after steady conditions were reached, the new readings were tabulated. This procedure was continued until the spark had been advanced by at least 12°. After the last distributor adjustment, the dynamometer and vehicle throttle were changed to another speed and load of interest, the distributor readjusted to obtain idle firing at top dead center and the entire procedure was repeated.

Air-fuel ratio tests were not conducted on the vehicles using gasoline as no adjustment would normally be made on fuel flow. The procedure followed when using CNG or propane was to adjust (while the vehicle was idling) the distributor for a specific spark advance and the basic gas flow adjustment to a very lean condition. The leanest setting possible on any one vehicle sometimes depended upon the speed and load to be used in the test. On the

[2] Trade names are used in this paper as a means for clear identification of the instrumentation used. Use of a trade name neither constitutes nor implies endorsement by the National Bureau of Standards.

1/2 ton truck using CNG, the idle gas pressure was adjusted generally to 1.5 inches of water gauge (and the tweeker adjusted as noted previously). On the 1/2 ton truck using propane, the restrictor was placed in the No. 2 position, (where No. 5 position was full open). On the 1 ton truck, the power valve was backed out 7 or 8 turns from full off (out of a possible 22 or 23 turns). After the truck was running at the required speed and load and all data had been recorded, the gas flow adjustment was then changed to a slightly richer position (1.5 inches of H_2O higher in idle gas pressure for the 1/2 ton truck using CNG, one number higher in restrictor position for the 1/2 ton truck using propane and 2 or 3 more turns out on the power valve for the 1 ton truck). This procedure was continued until the richest running possible was obtained and then the speed and load were changed and the entire procedure repeated.

RESULTS AND DISCUSSION

This paper is a presentation of selected examples of an extensive series of tests conducted on the vehicles. All the pertinent data that was obtained is included in reference (1).

In general, the dependence of the various pollutants on spark advance and air-fuel ratio was in agreement with reference (2). As the tests were conducted, suprisingly little dependence on temperature was observed. The air-fuel ratios were determined for CNG and LPG fueled tests by exhaust gas analysis. Reference (3) outlines the procedure for determining air-fuel ratios in this manner and additional charts not included in that report which govern the combustion of CNG and LPG were used in this study (Reference 4).

Figures 6, 7, and 8 show the results of typical spark advance tests conducted on the 1/2 ton truck at temperatures of approximately 110°F. The independent variable is idling spark advance and data is shown for NO_x while the vehicle was running at 50 mph and 30 hp and HC and CO at idling conditions respectively. The data shown here are for the conditions where the settings in the respective fuel systems were made to give the leanest possible running conditions (to minimize the pollutant levels) and yet deliver what was judged as acceptable power out of the vehicle (30 hp at 50 mph). The running conditions selected, 50 mph and 30 hp for NO_x and idle for CO and HC, are those which represent an upper limit on pollutants.

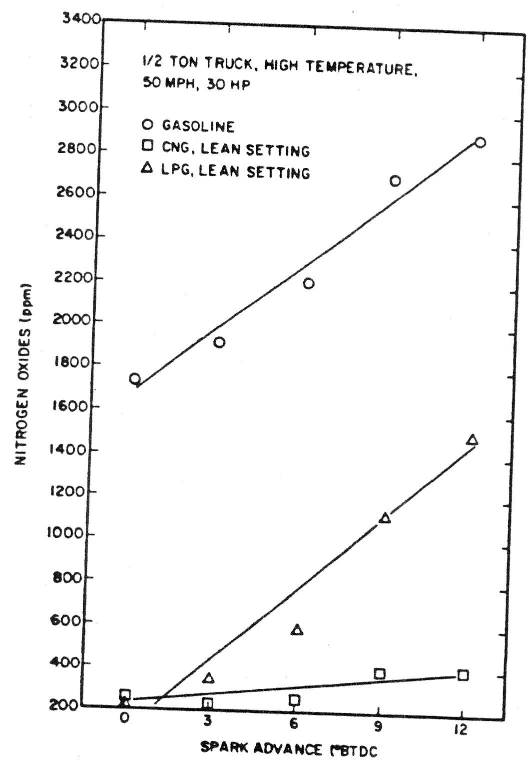

FIGURE 6 NITROGEN OXIDES VS SPARK ADVANCE FOR A 1/2 TON TRUCK USING GASOLINE, CNG AND LPG

It was found for the various spark advance tests that it was possible to maintain the pollutants below the following levels for an appropriate lean setting in the fuel system (no adjustment for gasoline) for ambient temperatures in the range (0 - 110°F):

6° BTDC idling spark advance

	NO_x (ppm)	HC (ppm)	CO (%)
CNG	300	50	0.1
gasoline	2400	215	1.2

0° BTDC idling spark advance

Propane	500	170	0.13
gasoline	1700	190	1.1

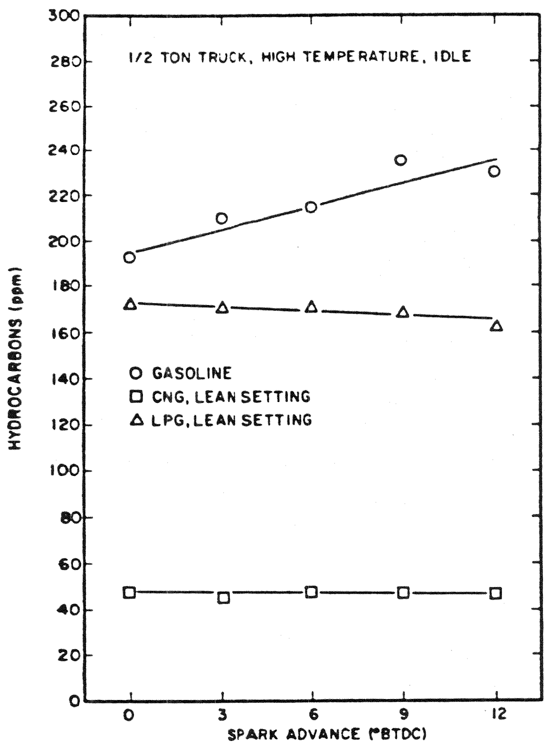

FIGURE 7 HYDROCARBONS VS SPARK ADVANCE FOR A 1/2 TON TRUCK USING GASOLINE, CNG AND LPG

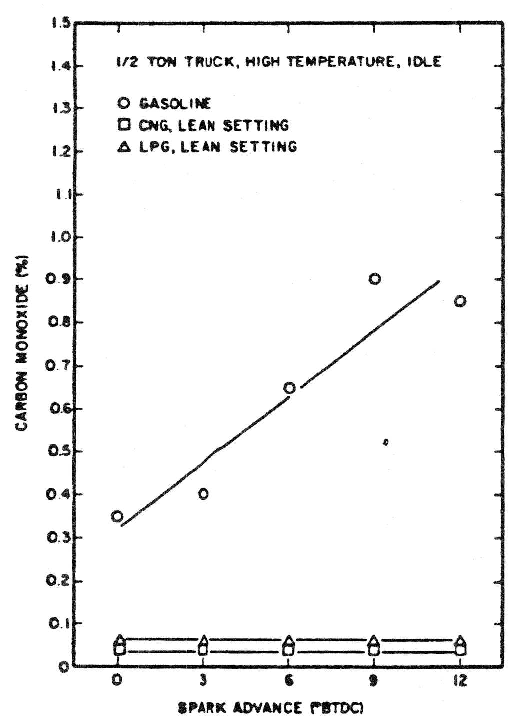

FIGURE 8 CARBON MONOXIDE VS SPARK ADVANCE FOR A 1/2 TON TRUCK USING GASOLINE, CNG AND LPG

Figures 9, 10, and 11 have been inserted to show a comparison between CNG and propane as fuels for this 1/2 ton truck during the air-fuel ratio tests. The comparison is made for 50 mph and 30 hp, and a given idling spark setting with the independent variable being the ratio of air-fuel ratio to stoichiometric air-fuel ratio. The NO_x content of the exhaust gas was a maximum closer to stoichiometric conditions for CNG than for propane. For a given value of (A/F) / (stoichiometric A/F) > 1.0, the NO_x content of the propane exhaust gas was higher than that of the CNG exhaust gas. As the mixture was enriched from a lean setting towards the stoichiometric condition, the CO and HC content of the exhaust gas did not rise significantly for CNG-fired tests until conditions to the rich side of stoichiometric were reached (all ambient temperatures). However, the increase occurred to the lean side of stoichiometric for the propane tests (all ambient temperatures).

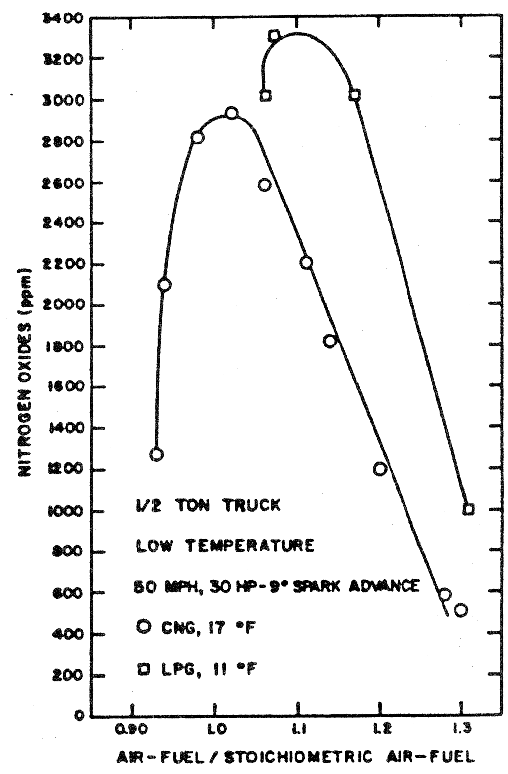

FIGURE 9 NITROGEN OXIDES VS NORMALIZED AIR-FUEL RATIO FOR A 1/2 TON TRUCK USING CNG AND LPG

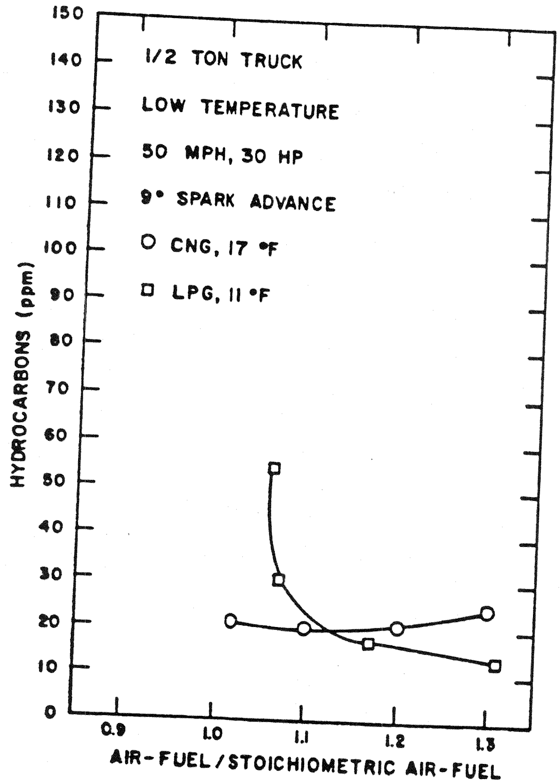

FIGURE 10 HYDROCARBONS VS NORMALIZED AIR-FUEL RATIO FOR A 1/2 TON TRUCK USING CNG AND LPG

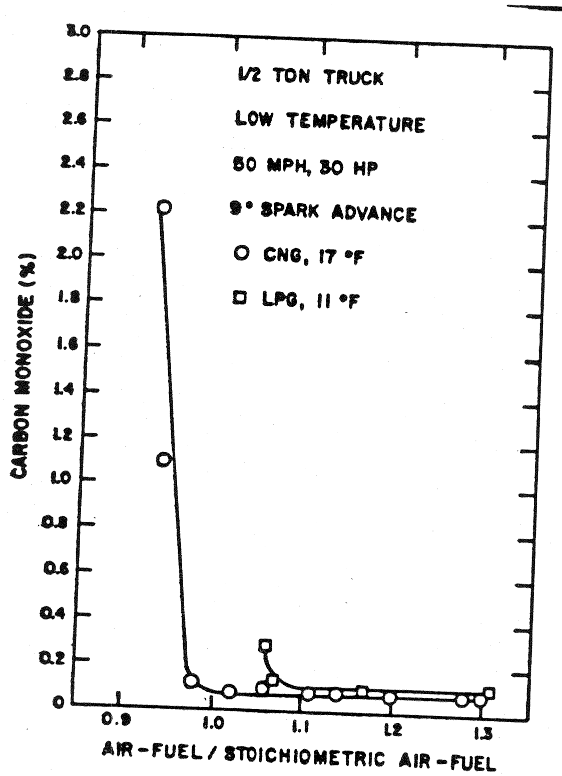

FIGURE 11 CARBON MONOXIDE VS NORMALIZED AIR-FUEL RATIO FOR A 1/2 TON TRUCK USING CNG AND LPG

Figure 12 shows the way in which the air-mixer and associated controls in the CNG system for the 1/2 ton truck affected a change in the air-fuel ratio as the vehicle was run faster and loaded down. For example, if the gas pressure were adjusted to 2 inch H_2O at idling conditions (550 rpm) and the tweeker adjusted as lean as possible (and yet a good idling obtained), an A/F ratio on the vehicle tested would be approximately 18. This is leaner than stoichiometric (17.4) thus giving complete combustion with a minimum of CO and HC. If the truck were run faster and loaded down with a constant air-fuel ratio, the HC would increase, CO remain the same, and NO_x increase tremendously. However, as can be seen in the actual system, the A/F decreased ultimately to about 22-1/2 at 50 mph and 30 hp. This caused a certain loss in available power; however, the vehicle tested still produced 30 hp and in addition, the NO_x was only 600 ppm.

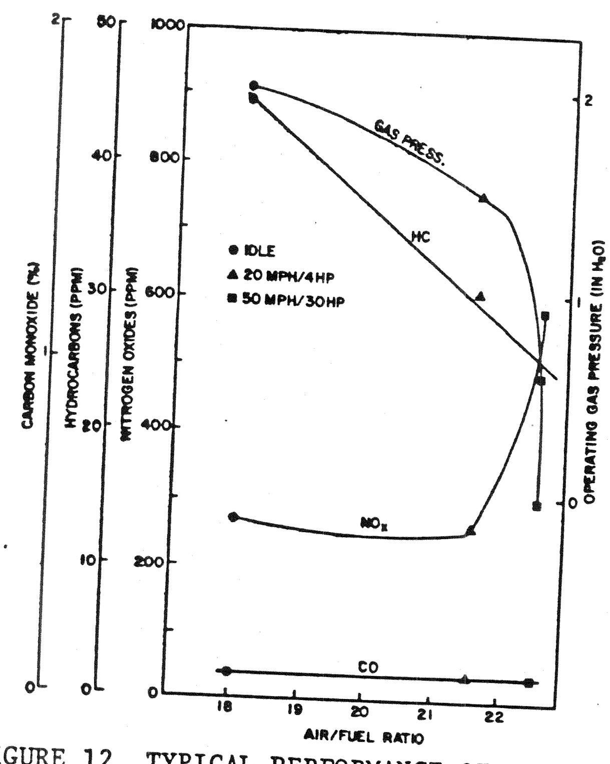

FIGURE 12 TYPICAL PERFORMANCE OF CNG SYSTEM FOR 1/2 TON TRUCK RESPONDING TO INCREASE IN DEMAND

Figure 13 shows that for any idle gas pressure setting the measured gas pressure, and thus available power, decreases with increasing demand in speed or load. This reduced pressure no doubt forced less fuel into the air mixer thus increasing the air-fuel ratio.

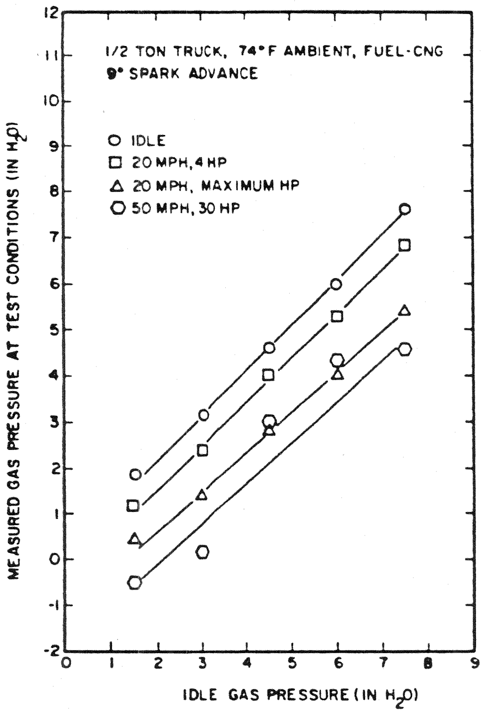

FIGURE 13 GAS PRESSURE AT RUNNING CONDITIONS VS IDLE GAS PRESSURE FOR A 1/2 TON TRUCK USING CNG

As noted previously, the CNG fuel system on the 1/2 ton truck was such that in addition to setting the second-stage regulator pressure, a screw-valve on the air mixer called a "Tweeker" had to be set to give a good idling condition. Figure 14 illustrates the magnitude of effect that the tweeker had on the resulting air-fuel ratio. For convenience of testing, the tweeker was adjusted at one specific idle gas pressure and then the vehicle's simulated road speed was increased to 50 mph. When changing the gas pressure (in order to obtain a different A/F ratio), it was simply increased or decreased by approximately 1.5 inch H_2O (with no readjustment of the tweeker) and data were taken. It was not important in these laboratory tests to readjust the tweeker after each change since different values of A/F ratio were all that were necessary. However, at 0° and 12° spark advance the tests were conducted twice, the tweeker being adjusted at the low end of the pressure range once and at the upper end before the second test. As can be seen, this difference in tweeker setting for a specified measured gas pressure caused a difference as large as 2 in the air-fuel ratio.

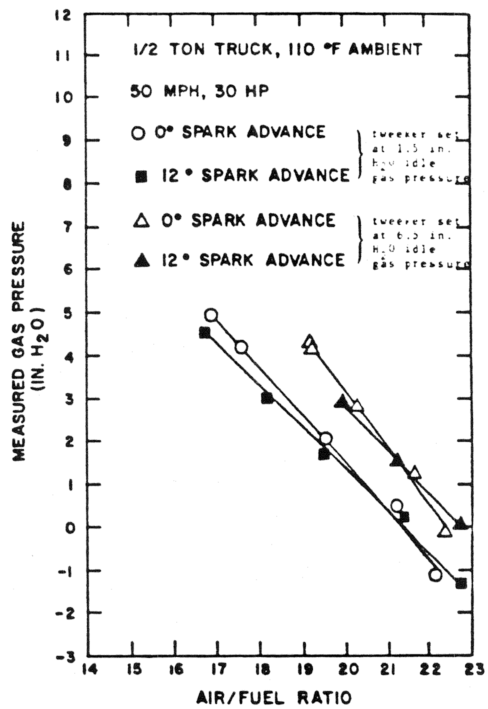

FIGURE 14 GAS PRESSURE AT RUNNING CONDITIONS VS AIR-FUEL RATIO FOR A 1/2 TON TRUCK USING CNG

When the propane system was used on the 1/2 ton truck, the fuel system adjustment was made solely with the flow restrictor or "power valve." Figure 15 is a plot of the air-fuel ratio as a function of specific restrictor positions at 6° BTDC idling spark advance, 50 mph and 30 hp and the three different ambient temperatures. The setting was critical in the vicinity of the number 2 position (No. 5 position - full open) in that a slight variation caused a considerable change in the resulting air-fuel ratio. The first position of the power valve was beyond the useful range for fuel control.

With the power valve or restrictor set at the lean position and for a given spark setting, the air fuel ratio increased or the mixture got leaner as the load and speed increased (see Figure 16). This was similar to the way the CNG dual-fuel system worked and seems to be best for minimizing the NO_x content of the exhaust gases. As the load and speed are increased, the NO_x would increase as we have already noted in Figure 9. However, this increase would be offset somewhat by the fuel regulating system operation whereby the mixture would simultaneously become leaner. Figure 17 shows that the power valve system behaved just the opposite when the restrictor was positioned for a rich running condition.

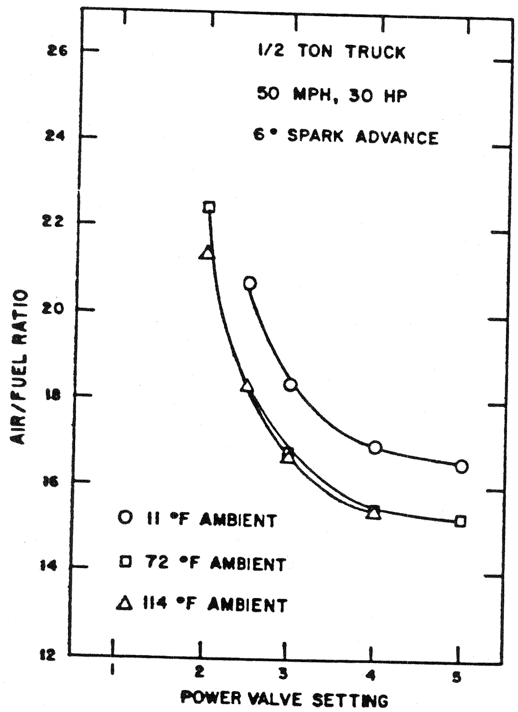

FIGURE 15 AIR-FUEL RATIO VS POWER VALVE SETTING FOR A 1/2 TON TRUCK USING LPG

Figures 18, 19, and 20 show data for the 1 ton truck when it was run on CNG and gasoline. The results are from a larger series of tests performed in the attempt to find the optimum settings for spark advance and air-fuel ratio. The criteria imposed was similar to the 1/2 ton truck tests in that idle mixture would be leaned so that at the perscribed power for each speed would be the maximum power available. This presumably would yield the minimum pollution while still offering a marginal vehicle performance. The tests were begun at 0° spark advance with the throttle wide open. At 50 mph the power valve, used for adjusting the gas flow in

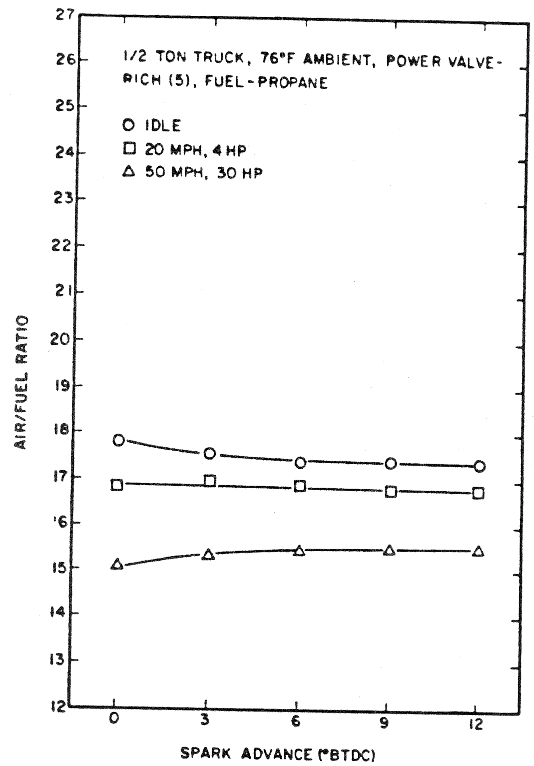

FIGURE 16 AIR-FUEL RATIO VS SPARK ADVANCE FOR A 1/2 TON TRUCK USING LPG

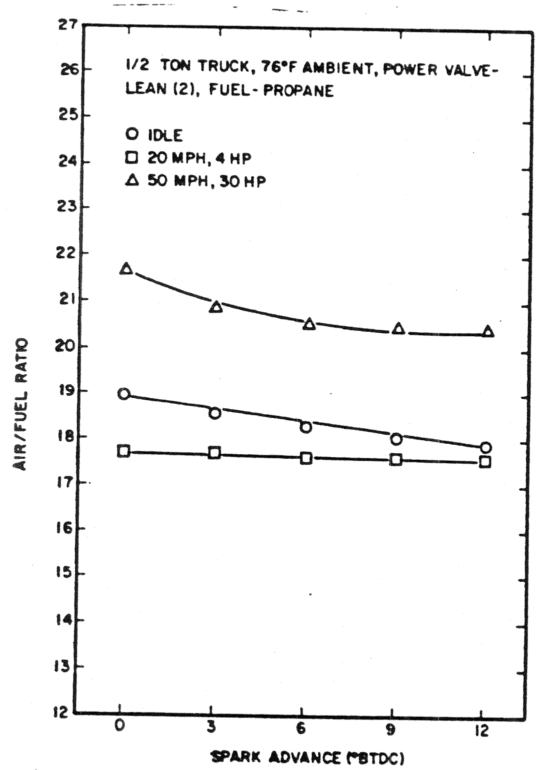

FIGURE 17 AIR-FUEL RATIO VS SPARK ADVANCE FOR A 1/2 TON TRUCK USING LPG

this system, was turned until the fuel rate was sufficient to produce only 30 horsepower at the wheels. During subsequent tests, as the spark was advanced and more power became available the power valve was turned in to limit the vehicle to 30 hp. These same settings were noted and then duplicated for the 20 mph and idle tests at each spark setting.

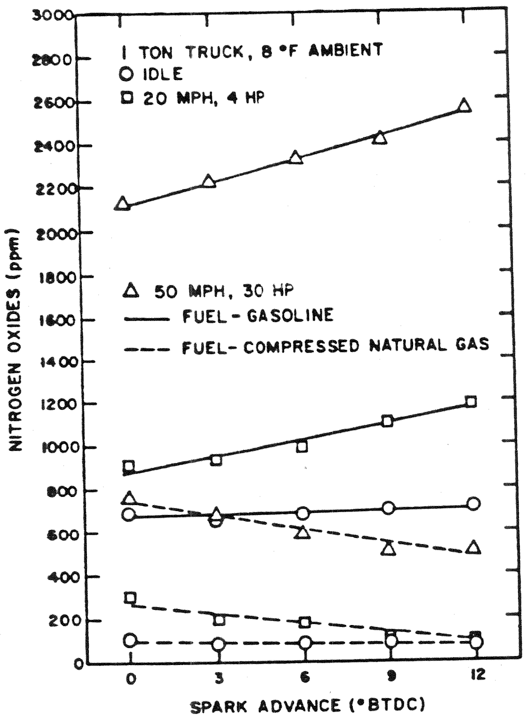

FIGURE 18 NITROGEN OXIDES VS SPARK ADVANCE FOR A 1 TON TRUCK USING CNG

As in the power valve (propane) tests of the 1/2 ton truck, the tendency for the NO_x to increase with increasing spark advance was offset by the leaning of the mixture. On the other hand, hydrocarbons tended to increase. As expected the carbon monoxide was so minimal that no change was detected.

Figures 21, 22, and 23 show the results of tests conducted to determine power capability of the 1 ton truck (and amount of associated pollutants) operating on CNG at a moderate environmental temperature. The way in which NO_x, HC and CO varied with air-fuel ratio was as expected. The change in spark advance from 0° before top-dead-center to 12° before top-dead-center produced a significant increase

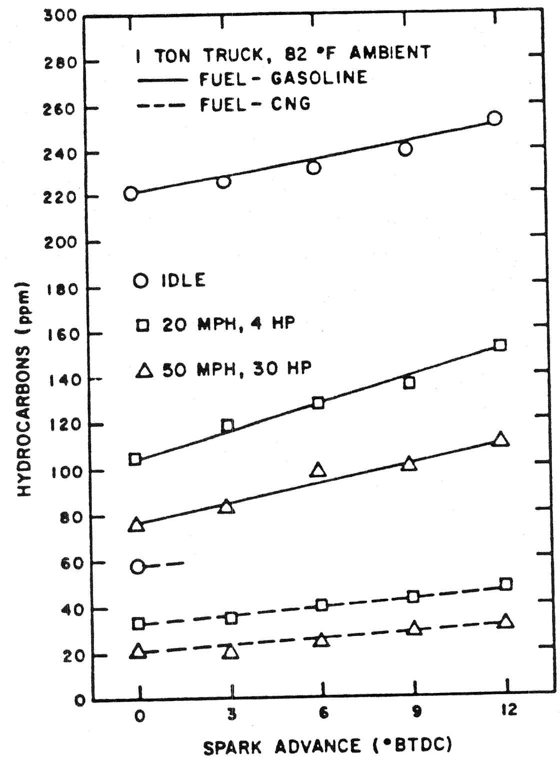

FIGURE 19 HYDROCARBONS VS SPARK ADVANCE FOR A 1 TON TRUCK USING CNG

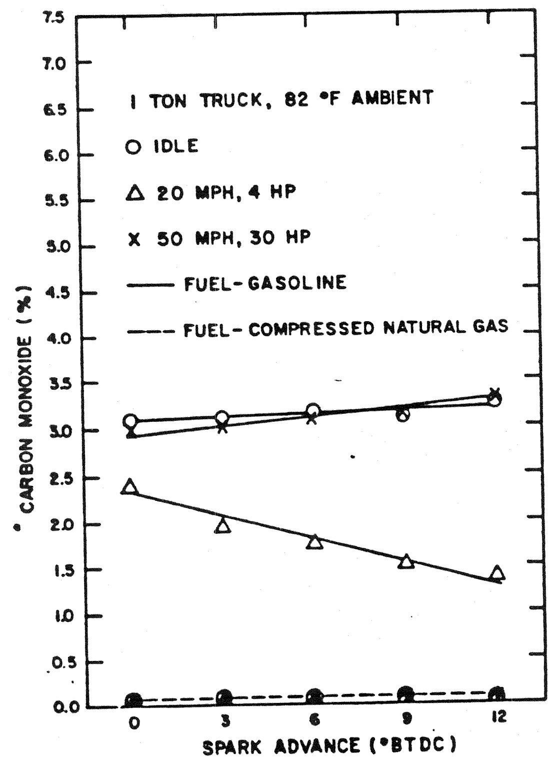

FIGURE 20 CARBON MONOXIDE VS SPARK ADVANCE FOR A 1 TON TRUCK USING CNG

in road horsepower with a corresponding increase in emissions, particularly NO_x. If the criteria for acceptable performance were 30 horsepower at 50 miles per hour, the curves show that it would be possible to maintain NO_x below some arbitrary level, say 1000 ppm, in various ways. For example, with a spark advance of 12° and an A/F ratio > 21.5 (see Figure 21) or with an advance of 0° and a leaner A/F ratio than 19. Checking the other emissions would suggest that of the two alternatives, less spark advance and rich mixture would be more advantageous in that there would be less hydrocarbons.

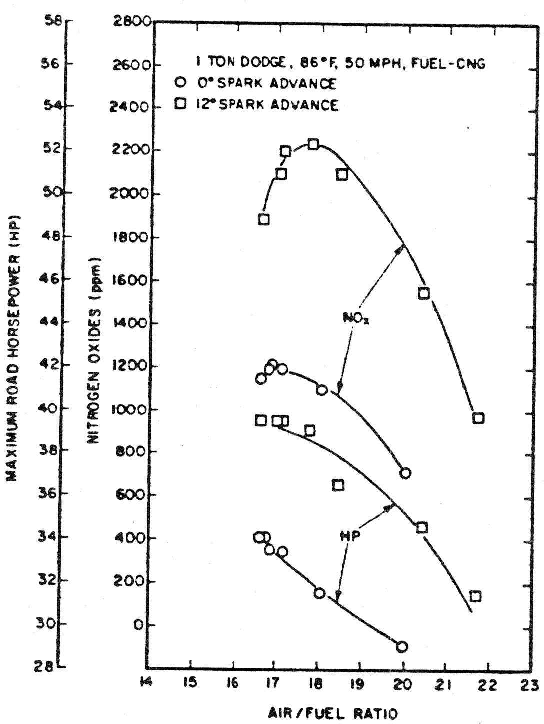

FIGURE 21 MAXIMUM HORSEPOWER AND NITROGEN OXIDES VS AIR-FUEL RATIO FOR A 1 TON TRUCK USING CNG AND OPERATING AT FULL THROTTLE

For this natural gas system, it has already been mentioned that a power valve in the form of a simple screw line obstruction, was used to vary the gas flow rate after the last stage pressure regulator. The results of a correlation between the valve settings and the A/F ratio are presented in Figure 24. An inspection of the mechanism, however indicated that it was not designed for precise repeatability in setting and it is questionable whether

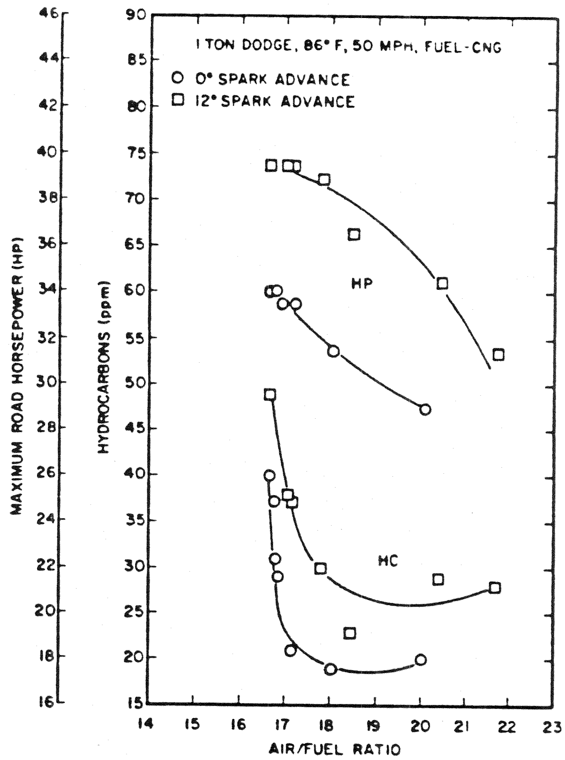

FIGURE 22 MAXIMUM HORSEPOWER AND HYDROCARBONS VS AIR-FUEL RATIO FOR A 1 TON TRUCK USING CNG AND OPERATING AT FULL THROTTLE

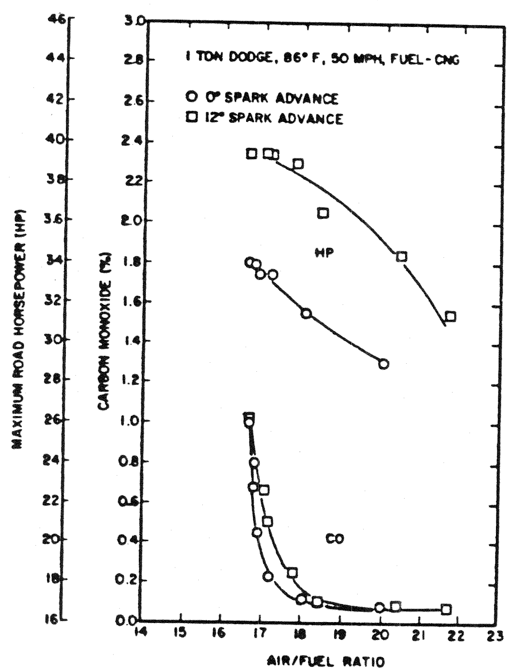

FIGURE 23 MAXIMUM HORSEPOWER AND CARBON MONOXIDE VS AIR-FUEL RATIO FOR A 1 TON TRUCK USING CNG AND OPERATING AT FULL THROTTLE

other similar valves using the same settings would yield these same results.

It was pointed out that the operation of the CNG fuel system for the 1/2 ton truck was such that for a given second stage regulator pressure and tweeker setting, the air-fuel ratio became leaner as the vehicle was run at higher speeds and loads. The same behavior was noted for the propane fuel system when a lean setting [2] was chosen. This is advantageous since the NO_x concentration would decrease significantly with the simultaneous leaning process. There appear to be indications that the fuel system for this second truck operated in the opposite way. In Figure 25, for two of the spark advance tests it can be seen that for a running condition of 20 mph/ 4 hp and 50 mph/ maximum horsepower for a power valve setting of 12-1/4 turns (where 23 turns - full open) the air-fuel ratio decreased with increasing demand. Such a response is compatible with the way in which ordinary gasoline carburetors behave; however, it is not the most desirable operation from the standpoint of minimizing NO_x emissions from idle fuel system adjustments.

The data that were taken during the laboratory study described in this paper showed that considerable reduction in emissions could be achieved throughout the load, speed, ambient conditions and spark timing range, of engines operated on natural gas or propane as opposed to gasoline. In addition, unique operating characteristics of the particular dual-fuel systems tested were determined.

As a "bench-mark", comparing test results to present data and future federal emission limits, Table 1 indicates the requirements and results of the 1/2 ton vehicle (3940 pounds) and the 1 ton vehicle (4700 pounds).[3] The range of test result data shown in the table are for carburetor and spark settings that would be chosen when using the respective sys-

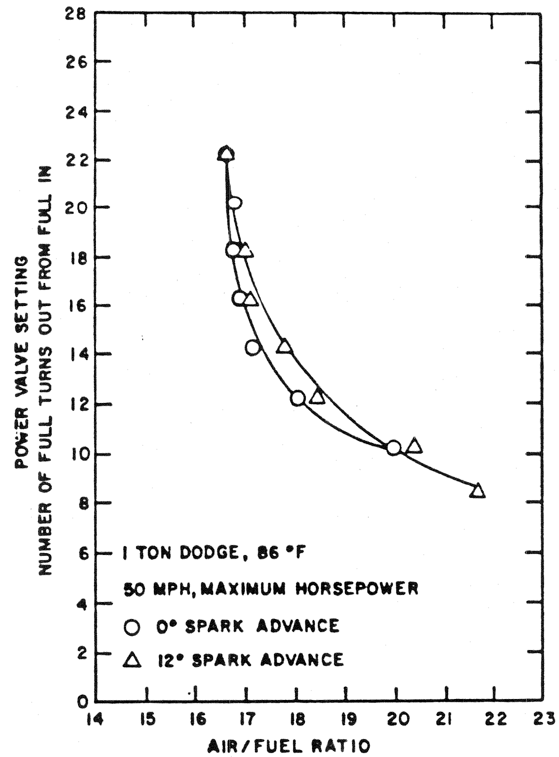

FIGURE 24 POWER VALVE SETTING VS AIR-FUEL RATIO FOR A 1 TON TRUCK USING CNG AND OPERATING AT FULL THROTTLE

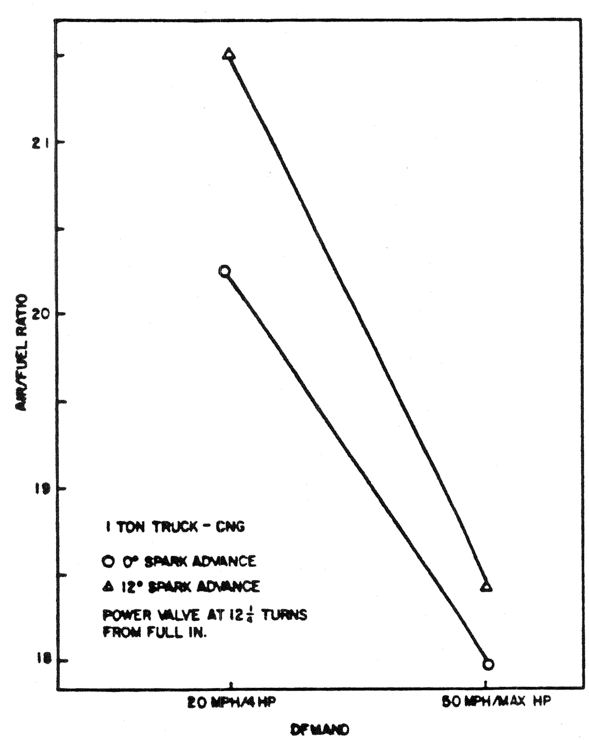

FIGURE 25 TYPICAL PERFORMANCE OF CNG SYSTEM FOR A 1 TON TRUCK RESPONDING TO INCREASE IN DEMANI

[3] Prior to introducing a mass emission measurement method into the regulations, a method was used whereby mass emissions were calculated from measured concentrations, a technique used in arriving at the federal limits in Table 1.

tems. It must be emphasized that the test data reflects performance curves and portable gas analysis instrumentation and has minimal relationship to the federal test requirements which are based upon critically controlled operating laboratory instrumentation. Further, the vehicles under test were both 1969 models, with minimal emission control equipment designed to satisfy requirements only for that year.

GENERAL COMPARISON OF EMISSIONS

NO_x (ppm)

Vehicles	1973-5 3.1 gm/mi	1976 .40 gm/mi	Test Results (Range)
1/2 Ton Truck (3940 lbs) Gasoline	771	102	300-2400
1/2 Ton Truck (3940 lbs) CNG	771	102	100-300
1/2 Ton Truck (3940 lbs) LPG	771	102	100-500
1 Ton Truck (4700 lbs) Gasoline	718	95	700-2300
1 Ton Truck (4700 lbs) CNG	718	95	75-1000

HC (ppm)

Vehicles	1972-4 3.4 gm/mi	1975-6 .41 gm/mi	Test Results (Range)
1/2 Ton Truck (3940 lbs) Gasoline	268	31	15-215
1/2 Ton Truck (3940 lbs) CNG	268	31	23-48
1/2 Ton Truck (3940 lbs) LPG	268	31	15-170
1 Ton Truck (4700 lbs) Gasoline	250	30	60-240
1 Ton Truck (4700 lbs) CNG	250	30	15-225

CO

Vehicles	1972-4 34 gm/mi	1975-6 3.4 gm/mi	Test Results (Range)
1/2 Ton Truck (3940 lbs) Gasoline	1.7%	0.14%	0.12-1.2%
1/2 Ton Truck (3940 lbs) CNG	1.7%	0.14%	0.05-0.12%
1/2 Ton Truck (3940 lbs) LPG	1.7%	0.14%	0.06-0.13%
1 Ton Truck (4700 lbs) Gasoline	1.5%	0.13%	0.2 -4.5%
1 Ton Truck (4700 lbs) CNG	1.5%	0.13%	0.02-0.1%

CONCLUSIONS

The use of natural gas or propane as a fuel for vehicles is clearly an improvement over gasoline from an emission viewpoint. In general it was possible to adjust the spark advance and air/fuel ratio such that the vehicles' emissions remained below the 1972-5 requirements while the vehicle's available power was adequate. Although the same was true for the 1976 carbon monoxide requirements, the hydrocarbons were borderline and the nitric oxides were definitely in excess of acceptable limits. The ambient temperature did not have a direct significant effect on the emission levels; although cold starting requirements did effect the initial adjustments.

The manner in which gaseous fuel systems responded to increased demand is of significance if adjustments are to be made at idle conditions. The fuel line values (i.e. pressure regulators, power values, etc.) may be set to limit the maximum amount of fuel so that when the throttle is opened and the air supply is increased the amount of fuel increase will be such that the air/fuel mixture will lean out with demand.

This phenomena is particularily evident in Figure 16 where under wide open power valve setting there was sufficient gas flow that the air/fuel mixture became richer as demand increased but when the power valve was partially closed, Figure 17, the air/fuel mixture ultimately became leaner with increasing demand. This latter case would allow for engine adjustments in the shop, under idle conditions, with assurance that the pollution rate will not be exceeded in the field.

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