# The Petro Electric Motors Hybrid Vehicle (Federal Clean Car Incentive Program Candidate Vehicle)

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Technology Assessment and Evaluation Branch
Emission Control Technology Division
Office of Air and Waste Programs
Environmental Protection Agency

## BACKGROUND

The Federal Clean Car Incentive Program (FCCIP) was initiated in 1970 to encourage industry to develop low emission vehicles. This is a multiphase program that starts with contractor prototype development and government testing (Phase I).

Petro Electric Motors, Ltd. (PEM) designed and constructed a vehicle to be submitted for Phase I testing under the FCCIP. Under contract 68-04-008 the vehicle was to be evaluated according to FCCIP - SPEC - 004, "Prototype Vehicle Test Specifications", over a ninety day period.

The Emission Control Technology Division (ECTD) of the Office of Mobile Source Air Pollution Control was requested by the Alternative Automotive Power Systems Division to conduct the required tests. The test program was conducted by the Technology Assessment and Evaluation Branch of ECTD.

## VEHICLE DESCRIPTION

The PEM vehicle is an internal combustion engine (ICE)/battery hybrid system installed in a 1972 Buick Skylark. The original ICE was replaced by the PEM hybrid system consisting of the 70 CID Mazda rotary engine and thermal reactor, electric dynamotor (motor/generator), and speed control circuits. These components are located in the engine compartment. Indicating meters, auxiliary vehicle controls, and manual controls for adjustment of engine air-to-fuel (A/F) ratio are located on the auxiliary dashboard inside the vehicle. The batteries and remaining speed control circuits are in the vehicle trunk (See Figure 1). Specifications for the car are contained in Table 1 - Test Vehicle Description.

The basic idea is to use a small ICE for average vehicle power requirements, with power assist from an electric motor operated from batteries for higher power requirements. The concept is an attempt to operate the engine over a restricted portion of the engine map in the belief that both low emissions and good fuel economy might be attained simultaneously. The replacement engine is considerably smaller than the original engine and therefore operates at a higher fraction of its peak power during average driving, thus hopefully achieving better efficiency. It is hoped that emissions can be maintained at low levels by proper controls since engine power transients are greatly reduced and the engine is operated over a restricted portion of the engine map. Regenerative braking is also used in an attempt to improve fuel economy.

Table 1

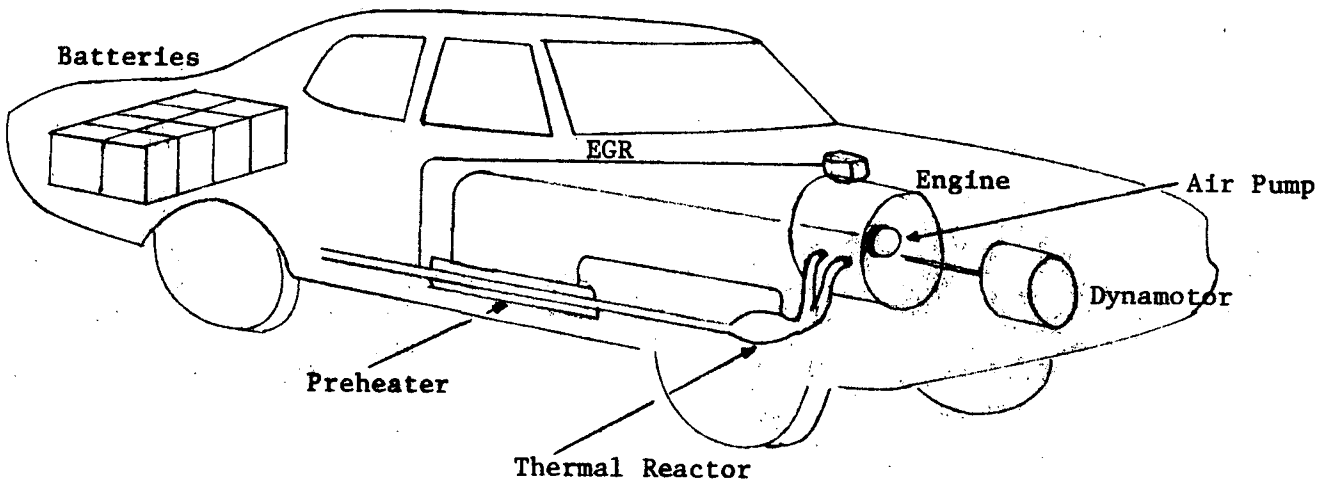
TEST VEHICLE DESCRIPTION

Chassis model year/make - 1972 Buick Skylark Sedan
Emission control system - Thermal Reactor, Air Injection, EGR

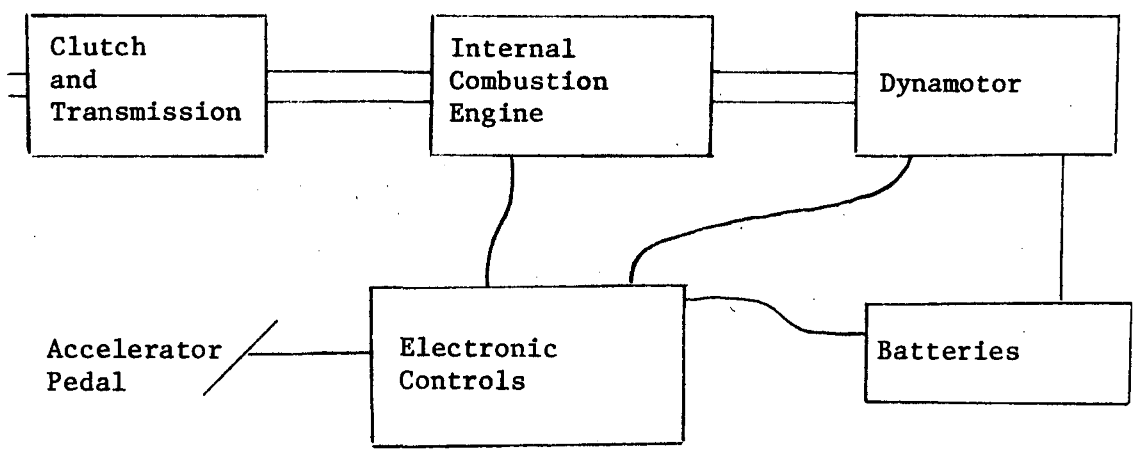
| | |
|---|---|
| **Engine** | |
| type . . . . . . . . . . . . . . . . | Mazda rotary, 2 rotors, Otto Cycle; trailing spark plug not fired |
| displacement (CID/cc) . . . . . . | 2 x 35.0/2 x 573.5 |
| compression ratio . . . . . . . . | 9.4:1 |
| maximum power @ rpm . . . . . . . | 130 hp/97 kW @ 7000 rpm |
| fuel metering . . . . . . . . . . | 4 bbl carburetor |
| fuel requirement . . . . . . . . . | 91 RON unleaded** |
| electric motor . . . . . . . . . . | Porter 60 hp/44.7 kW @ 5500 rpm, D.C., with 120 volt separately excited shunt field |
| electric power supply . . . . . . | eight 12-volt lead-acid batteries |
| **Drive Train** | |
| transmission type . . . . . . . . | 3-speed manual (ratios 3.0, 1.85, 1:1) |
| final drive ratio . . . . . . . . | 5.0:1 |
| **Chassis** | |
| type . . . . . . . . . . . . . . . . | body-on-frame, front engine and electric motor, rear wheel drive |
| tire size . . . . . . . . . . . . | H 78 x 14 (GR 78 x 14 in Part III tests) |
| curb weight . . . . . . . . . . . | 4135 lb/1875 kg |
| inertia weight . . . . . . . . . . | 4000 lb* |
| passenger capacity . . . . . . . . | 6 |
| steering and brakes . . . . . . . | non-power assisted |
| **Emission Control System** | |
| basic type . . . . . . . . . . . . | thermal reactor |
| thermal reactor type . . . . . . . | standard Toyo Kogyo unit (with temperature control for choke operation during Part I and II test) |
| volume . . . . . . . . . . . . . | not available |
| air injection . . . . . . . . . . | preheated, unmodulated |
| size pump . . . . . . . . . . | not available |
| drive ratio . . . . . . . . . | 0.80:1 |
| location . . . . . . . . . . . | exhaust port |
| EGR type . . . . . . . . . . . . . | hot, manual on/off |
| rate . . . . . . . . . . . . . . | 10-25% (estimated by PEM) |
| evaporative controls . . . . . . . | carbon canister |

* Although the vehicle was 185 to 685 pounds heavier than vehicles which would be certified at 4000 pound inertia weight, the 4000 pound setting was used here because the contractors claimed that the weight could be reduced without affecting performance and also since the contractor had done all development work and testing at the 4000 pound inertia weight.

** Basic engine system does not require unleaded fuel, however Mazda, the engine manufacturer, recommends unleaded fuel in their vehicles.




Emission and Powertrain Component Layout




Powertrain Block Diagram

Figure 1 - Component Location and Function

The dynamotor is permanently coupled to the front of the rotary engine crankshaft and rotates at the same speed. Power generated by the engine and the dynamotor (under certain high power conditions) is transmitted to the rear wheels through a clutch and transmission at the rear of the engine. Engine power is controlled to maintain a constant manifold vacuum. Depending on driving load requirements, additional power is either provided by the dynamotor with electric current drain from the batteries, or absorbed by the dynamotor to generate charging current to the batteries. The eight 12 volt lead/acid batteries supply either 50 volts (low speeds) or 100 volts (rapid acceleration and high speeds) depending on load requirements. Dynamotor operation is controlled by the accelerator pedal and electronic controls that monitor ICE manifold vaccum. Through this control the dynamotor field current and engine throttle position are adjusted to maintain constant manifold vacuum. Depending upon field current the batteries will either charge or discharge. For higher power demands, depression of the accelerator overrides these controls to open the throttle for greater engine power output.

The PEM Emission control technique is based on use of a thermal reactor for hydrocarbon (HC) and carbon monoxide (CO) control and exhaust gas recirculation for nitrogen oxides (NOx) control of an engine operating over a restricted engine map. HC and CO are controlled by maintaining the proper ratio of combustibles to secondary air in the thermal reactor. This is achieved by adjusting the engine A/F ratio to keep the thermal reactor temperature at 1650$^{o}$F. Simultaneously, sufficient EGR is added to control NOx. A preheater for the reactor secondary air reduces the tendency of the reactor to quench due to carburetor enleanment during transmission gear changes and permits use of a leaner A/F ratio.

During the initial tests, the A/F ratio of stock carburetor varied considerably with engine speed. To compensate for this variation a second vehicle operator/technician is required to continuously control A/F ratio by adjusting a choke butterfly valve. The second operator is also required to adjust manifold vacuum and turn on EGR during the test.

For the last tests, Part III, the vehicle emission control system was modified. This reduced the second operator's tasks to a timed sequence during a limited time after vehicle startup. (See Table VIa).

## TEST PROCEDURE

The FCCIP Prototype Vehicle Specifications were followed in part. The TAEB test conductor authorized omissions and deviations from FCCIP SPEC - 004 in the interests of time or if no test was deemed necessary due to vehicle's essentially stock condition.

The main emphasis was to acquire gaseous exhaust emissions data. Other tests were run to define performance, safety, noise, and emissions of aldehydes. Exhaust emission tests were conducted according to the 1975 Federal Test Procedures (75 FTP) described in the Federal Register of November 15, 1972. Additional tests included the EPA Highway Cycle. Most testing was done at an inertia weight of 4000 pounds (1814 kg) with a road load setting of 12.0 horsepower (8.95 kW) at 50 miles per hour (80.5 km/hr.). This is the standard road load for non-air conditioned vehicles. The actual vehicle weight would normally put the vehicle in the 4500 pound (2041 kg) inertia weight class. However, since it was a prototype for a 4000 pound class of vehicles, it was usually tested at the 4000 pound weight.

No durability mileage was accumulated.

Noise testing consisted of the SAE 986a driveby exterior noise test.

Performance testing was limited to vehicle acceleration tests using a 5th wheel.

Aldehyde emissions in vehicle exhaust were measured using a wet chemical method (MBTH).

## TEST RESULTS

The test program was divided into three time periods during the year. This occurred because the EPA Highway Cycle was developed shortly after the initial testing was concluded, and because of the decision to retest the vehicle after modifications were made.

## PART I

Upon arrival the vehicle was inspected and certain components under the hood were required to be more positively fastened. The required Federal Motor Vehicle Safety Standards were still met by the vehicle chassis. The vehicle was test-driven on local streets and highways at speeds up to 60 mph (96.6 km/hr.). Engine noise was noticeable at high speeds but judged to be not objectionable. Due to the placement of the motor and batteries in this prototype vehicle, considerable weight was added near the ends of the vehicle. This adversely affected steering and braking, both requiring considerable effort to control the vehicle safely. PEM attributes this effect to the loss of braking effect due to the high idle speed (2000 RPM).

The first set of emission tests were voided when it was discovered by PEM that the motor had been improperly wired during PEM refurbishing prior to EPA testing. The thermal reactor secondary air preheater was reconnected shortly after testing resumed. Several vehicle, procedural, and equipment problems were encountered. Also many tests did not show the system's emission control capability due to error by the second operator in adjusting the A/F ratio. The result was that no tests were obtained in which the vehicle achieved the low emission levels claimed by PEM.

However, many of the malfunctions caused only momentary failures. Often this affected only one of the pollutants or only emissions in one of the three sample bags. Therefore, if certain emissions results are eliminated, it is possible to average the remaining to obtain exhaust emission values.

Tests with the fewest problems were selected and are listed in Tables II a and II b (individual bag data) and Table III (75 FTP composite mass emissions). Average results are:

75 FTP Composite Mass Emissions
grams per mile
(grams per kilometre)

| HC | CO | NOx | Fuel Economy (Fuel Consumption) |
|---|---|---|---|
| .46 | 2.06 | 1.04 | 8.9 miles/gal |
| (.35) | (1.28) | (.64) | (26.5 litres/100 km) |

The value of HC exceeds the level of the Phase I requirement by 12 percent, and the NOx value exceeds the level of the Phase I requirement by 4 percent. The CO levels were met. These values do not consider vehicle emissions deterioration factors since the vehicle was tested at low mileage.

One LA-4 (urban) driving cycle was run with vehicle shutdown during long idle periods since one approach to improving fuel economy and avoiding overcharging the batteries during idle periods would be to shutdown the vehicle during stops. This resulted in a thirty percent improvement in fuel economy. However, HC and CO increased several hundred percent, while NOx decreased twenty percent (See Table II b). The magnitude of these emissions could probably be reduced since no serious attempt was made to optimize emission control for this type of operation. Results were:

72 FTP Hot Start Composite Mass Emissions
grams per mile
(grams per kilometre)

| HC | CO | NOx | Fuel Economy (Fuel Consumption) |
|---|---|---|---|
| 2.22 | 9.02 | .84 | 11.6 miles/gal |
| (1.38) | (5.61) | (.52) | (20.3 litres/100 km) |

But, since the batteries receive most of their recharge during idle, the result indicates what would be expected if the batteries discharge during the cycle.

Two 1975 FTP's were conducted at 4500 pounds and a road load setting of 12.7 hp (9.47 kW) (Table II b). These would be the test conditions if the vehicle were to be tested for certification (without air conditioning). Both these are listed below since there was considerable test-to-test variation in pollutants.

75 FTP Composite Mass Emissions
grams per mile
(grams per kilometre)

| HC | CO | NOx | Fuel Economy (Fuel Consumption) |
|---|---|---|---|
| 2.78 (1.73) | 20.4 (12.7) | 1.16 (.72) | 9.4 miles/gal (25. litres/100 km) |
| .66 (.41) | 3.88 (2.41) | .86 (.53) | 8.9 miles/gal (26.4 litres/100 km) |

Battery voltages were taken before testing and several hours after completion of testing. There was considerable variation in the net charge (See Table III). However the testing procedures for measuring battery voltage were not refined until Part III.

Aldehydes were measured during the initial tests which were later voided. Time did not permit a repeat of the aldehyde test. For the two tests the composite results gave very low values. The results are:

| Aldehydes grams per mile (grams per kilometre) | HC grams per mile (grams per kilometre) |
|---|---|
| .037 (0.23) | 2.15 (1.34) |
| .032 (.020) | .62 (.39) |

These levels are as low as those from any other vehicle tested and, since these HC values are considerably higher than the test results, the car can be expected to be very low in aldehyde emissions.

The evaporative emission controls were not connected and therefore no attempt was made to collect evaporative emission data. However, no problems would be anticipated in incorporating a complete evaporative emission system. The effects of the evaporative losses on vehicle emissions was therefore not measured, however, in the judgement of EPA personnel, with a proper system the effect should be minimal. It accelerated well during the emissions test. However, it did backfire many times and stalled during several tests. The car always started readily. The transmission, which was a Vega transmission installed in a Buick body, was often difficult to upshift and on occasion it would take several seconds to change gears. Additional cooling air was always provided by the test laboratory for the batteries in the trunk.

At the end of the first test period, the vehicle was taken to a test track for acceleration and noise testing. Acceleration results are listed in Table IV. Average results are:

Vehicle Acceleration
(4950 lb. Test Weight)

| Speed mpg (km/hr) | Average Times (seconds) Standard Configuration | Without Batteries |
|---|---|---|
| 20 (32.2) | 3.2 | 4.2 |
| 30 (48.3) | 5.8 | 7.5 |
| 40 (64.4) | 9.4 | 11.8 |
| 50 (80.5) | 12.5 | 16.2 |
| 60 (96.6) | 17.5 | 24.2 |

The difficulty in shifting increased the times above 20 mph by approximately one second. Noise results are given in Table V. There overall noise level reported per SAE J 986a is 79 db(a).

PART II

The vehicle was available in early May for a limited number of tests. Since the EPA Highway Cycle had been recently developed, the vehicle was tested to determine its highway fuel economy and to establish if its ratio of EPA Highway Cycle economy to LA-4 economy was unique. The results of the first two tests (Table III) showed considerable variation. Therefore a '75 FTP was run to establish if the car still operated as before and two additional EPA Highway Cycle fuel economy tests were run. Results (test no. 21-4331, Tables II b and III) showed the vehicle to be operating at HC and CO emission levels greatly above the previous tests. The result was:

'75 FTP Composite Mass Emissions
grams per mile
(grams per kilometre)

| HC | CO | NOx | Fuel Economy (Fuel Consumption) |
|---|---|---|---|
| 6.50 | 15.6 | .85 | 9.9 miles/gal |
| (4.03) | (9.69) | (.52) | (23.8 litres/100 km) |

This indicated that possibly the vehicle was no longer in the former operating condition and therefore the highway fuel economy results were not representative of its true performance. For these conditions the average indicated fuel economy was 23.2 mpg (10.2 litres/ 100 km). (The test on May 2nd appeared to be significantly lower and is not included in this average). The car batteries gave a net discharge during the EPA Highway Cycle. Therefore, the car could not continue this cycle and the indicated fuel consumption did not show the true energy consumption. After the last cycle one of the batteries showed a low voltage and one battery cell appeared damaged.

## PART III

Because of the effects on emissions and fuel economy of different levels of energy storage in the batteries and other unique characteristics, additional tests were performed. The object was to repeat the emissions tests while maintaining the batteries at well defined conditions.

Vehicle controls had been sufficiently altered, (Table VIa) so that the second operator's schedule could be accomplished reliably. Other vehicle modifications which had been performed were re-jetting the carburetor, a new set of eight 12 volt batteries, radial tires, and control system changes (Table VIb).

The '75 FTP is an emissions test designed to simulate cold and hot start trips. This is a four bag procedure. Bags 2 and 4 should be identical since they are both hot tests of the same driving cycle. Thus normally only three bags are taken and then a weighted average is calculated. However the PEM hybrid can store energy in one portion of the cycle and use it in another. A more representative test would therefore be the four bag procedure planned for this series.

Battery conditions were to be the same before and after each test. The voltage of each battery and specific gravity of one cell per battery would be used to determine battery state-of-charge. State-of-charge was to be determined before each test. To permit battery equilibrium, measurements were to be taken no sooner than four hours after operating the vehicle. To measure accurately the effect of driving the vehicle, the vehicle was not operated except during the driving cycles. (Thus it was pushed on and off the dynamometer.)

Four tests were planned:

- '75 FTP with balanced battery state-of-charge
- EPA Highway Cycle with FTP settings (net discharge)
- EPA Highway Cycle with balanced state-of-charge
- '75 FTP with above Highway settings

The vehicle arrived and necessary adjustments were made by PEM to maintain low emissions without changing battery conditions. This was a time consuming iterative task since these were cold start tests and battery conditions were required to be the same before and after each test. To balance state-of-charge for the EPA Highway Cycle, EGR was reduced, since this was the most straightforward approach and allowed the test to be performed in the time remaining. The results are given in Table VII and are summarized below.

Emissions
grams per mile
(grams per kilometre)

| | HC | CO | NOx | Fuel Economy (Fuel Consumption) |
|---|---|---|---|---|
| 75 FTP<br>Balanced Charge | .38<br>(.24) | 2.41<br>(1.50) | .76<br>(.47) | 8.8 miles/gal<br>(26.7 litres/100 km) |
| EPA Highway<br>Unbalanced Charge<br>(Batteries Discharged) | .13<br>(.08) | 1.09<br>(.68) | .60<br>(.37) | 18.2 miles/gal<br>(12.9 litres/100 km) |
| EPA Highway<br>Balanced Charge | .01<br>(.01 | .10<br>(.07) | 1.59<br>(1.00) | 15.6 miles/gal<br>(15.1 litres/100 km) |
| 75 FTP<br>Unbalanced Charge<br>(Batteries Charged) | .32<br>(.20) | 2.16<br>(1.34) | 3.29<br>(2.04) | 7.0 miles/gal<br>(33.6 litres/100 km) |

The unbalanced 75 FTP was limited to 11.1 miles to prevent severe battery overcharge. In contrast to the initial vehicle tests, no backfire problems were experienced during this series of tests.

To determine the battery condition at the conclusion of testing, the batteries were fully charged and discharged after the last test. The battery energy capacity was near the manufacturer's rating. One battery was observed to have a damaged cell during this test.

The results of the Part III tests are more conclusive than Part I and Part II since the vehicle operating parameters were well known.

The ratio of balanced EPA Highway Cycle fuel economy to balanced 75 FTP fuel economy is 1.77. For most conventional vehicles this ratio is between 1.3 and 1.7 for all inertia weight classes. This result may not be fully representative of what may be achieved through vehicle developmental testing by PEM since the adjustments made were probably not optimum.

## CONCLUSIONS

The vehicle demonstrated the Phase I exhaust emission levels of .41 gm/mi HC, 3.4 gm/mi CO, and 1.0 gm/mi NOx during the 40 miles of testing in the last test configuration. However, the deterioration factor was not established since this was a low mileage vehicle.

The evaporative emission controls were not tested. In its present condition the vehicle cannot be driven by an inexperienced driver over an arbitrary route since there are no automatic provisions for battery control. In addition a second operator is required to operate the emission controls for a limited time after vehicle startup.

# APPENDIX
# TEST RESULTS

TABLE II a

MASS EMISSIONS
GRAMS PER MILE

| | Bag 1 Cold Transient HC | CO | $CO_2$ | NOx | Fuel Economy MPG | Bag 2 Hot Stabilized HC | CO | $CO_2$ | NOx | Fuel Economy MPG | Bag 3 Hot Transient HC | CO | $CO_2$ | NOx | Fuel Economy MPG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16-1164 | 1.67 | 4.28 | 781.6 | .82 | 11.2 | .07(1) | 2.61(2) | 1150.5 | .87 | 7.7 | .56(3) | 4.46(4) | 789.7 | .93 | 11.1 |
| 15-60 | 1.63 | 2.84 | 841.5 | 1.04 | 10.4 | .04 | 1.36 | 1293.4 | 1.36(5) | 6.8 | .55(3) | 2.62 | 804.7 | 1.10 | 10.9 |
| 15-61 | 1.47 | 6.63(6) | 789.6 | .88 | 11.0 | .11(1) | 3.56(2) | 1204.0 | .84 | 7.3 | .66(3) | 2.74 | 780.2 | .80 | 11.3 |
| 15-76 | 1.50 | 3.29 | 805.6 | .83 | 10.9 | .04 | 1.35 | 1246.4 | 1.52 | 7.1 | .39 | 2.56 | 818.6 | 1.44(7) | 10.8 |
| 15-77 | 2.50(8) | 6.14(8) | 776.7 | .67 | 11.2 | .21(6) | 1.43 | 1177.6 | 1.28 | 7.5 | .37 | 3.05(8) | 700.4 | .99 | 12.6 |
| 15-78 | 2.41(9) | 7.85(9) | 730.1 | 1.01 | 11.8 | .05 | .90 | 1064.8 | 1.17 | 8.3 | .68(9) | 10.32(9) | 751.1 | 1.18 | 11.5 |
| Average (Excludes those with comments 2 to 9) | 1.57 | 3.47 | 787.5 | .87 | 11.1 | .06 | 1.20 | 1189.4 | 1.13 | 7.4 | .38 | 2.64 | 774.2 | 1.00 | 11.4 |

(1) Suspect due to break in exhaust pipe. Used in average.
(2) Second operator had difficulty positioning choke during shifts.
(3) Bad start due to possible fuel percolation.
(4) Late reactor lite off/second operator.
(5) EGR valve shifted position.
(6) Out of line with what can be obtained.
(7) No EGR.
(8) Loss of power.
(9) Leak in secondary air cause difficulty in lite off.

TABLE II b

MASS EMISSIONS
GRAMS PER MILE

| Test Number | Bag 1 Cold Transient HC | CO | $CO_2$ | NOx | Fuel Economy MPG | Bag 2 Hot Stabilized HC | CO | $CO_2$ | NOx | Fuel Economy MPG | Bag 3 Hot Transient HC | CO | $CO_2$ | NOx | Fuel Economy MPG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 15-79 (1) | | | | | | 1.60 | 4.72 | 915.2 | 1.14 | 9.6 | 2.89 | 13.70 | 553.9 | .51 | 15.2 |
| 15-80 (2) | 5.70 | 41.12 | 697.8 | .86 | 11.4 | .12 | 2.29 | 1128.3 | 1.39 | 7.8 | 5.66 | 39.53 | 633.8 | .93 | 12.4 |
| 15-81 (2) | 1.87 | 4.54 | 818.4 | 1.05 | 10.7 | .26 | 3.94 | 1169.4 | .88 | 7.5 | .05 | 3.27 | 782.6 | .68 | 11.2 |
| 21-4331 (3) | 3.17 | 14.11 | 715.5 | .99 | 11.9 | 4.70 | 18.55 | 969.6 | .61 | 8.8 | 12.44 | 11.18 | 732.6 | 1.22 | 11.2 |

(1) Hot Start shutdown during long idle.

(2) 4500 pound inertia weight test.

(3) 1975 FTP to confirm vehicle condition after highway cycle.

## TABLE III

## WEIGHTED EMISSIONS
## GRAMS PER MILE

| Test Number | Date | HC | CO | $CO_2$ | NOx | Fuel Economy MPG | Average Battery Volts |
|---|---|---|---|---|---|---|---|
| 16-1164 | MAR 1 | .53 | 3.46 | 976.1 | .88 | 9.0 | After 1.231 S.G.<br>Before 1.246 S.G.<br>-.015 |
| 15-60 | MAR 4 | .51 | 2.01 | 1067.1 | 1.22 | 8.3 | After 12.47<br>Before 12.46<br>.01 |
| 15-61 | MAR 5 | .54 | 3.97 | 1003.1 | .84 | 8.8 | After 12.47<br>Before 12.48<br>-.01 |
| 15-76 | MAR 14 | .44 | 2.08 | 1038.9 | 1.36 | 8.5 | After 12.58<br>Before 12.38<br>.20 |
| 15-77 | MAR 15 | .93 | 3.5 | 979.2 | 1.06 | 9.0 | After 12.37<br>Before 12.58<br>-.19 |
| 15-78 | MAR 18 | .71 | 4.90 | 910.3 | 1.14 | 9.6 | After 12.71<br>Before 12.37<br>.34 |
| 15-79 | MAR 19 | 2.22 | 9.02<br>SHUTDOWN DURING LONG IDLES | 742.3 | .84 | 11.6 | Hot Start |
| 15-80 | MAR 19 | 2.78 | 20.4<br>4500 LB. INERTIA WT. TEST | 904.8 | 1.16 | 9.4 | After (Hot) 12.56<br>Before 12.71<br>-.15 |
| 15-81 | MAR 22 | .66 | 3.88<br>4500 LB. INERTIA WT. TEST | 991.6 | .86 | 8.9 | After (Hot) 12.40<br>Before 12.59<br>-.19 |
| 15-4108 | MAY 2 | .02 | 1.08 | 540.7 | 1.42 | 16.4 | HWY Cycle |
| 15-4211 | MAY 8 | .07 | 4.55 | 352.8 | 1.54 | 24.6 | HWY Cycle |
| 21-4331 | MAY 16 | 6.50 | 15.6 | 853.0 | .85 | 9.9 | Before 12.30 |
| 21-4331 | MAY 16 | .13 | 1.34 | 376.3 | 1.80 | 23.4 | HWY After 12.59 |
| 21-4332 | MAY 16 | .01 | 2.14 | 408.4 | .83 | 21.5 | HWY After 11.79 |

# TABLE IV

## VEHICLE ACCELERATION RESULTS

| MPH | TIME (SECONDS) WEST | EAST | EAST | WEST | WEST | EAST |
|---|---|---|---|---|---|---|
| 20 | 3.4 | 3.0 | 3.2 | 3.0 | 3.5 | 3.0 |
| 30 | 5.3 | 5.4 | 5.8 | 6.0 (.9 sec shift) | 6.2 | 5.8 (.7 sec shift) |
| 40 | 11.4 (2.5 sec shift) | 9.1 (.8 sec shift) | 8.9 (1 sec shift) | 8.7 | 10.0 (.8 sec shift) | 8.4 |
| 50 | 14.3 | 12.7 | 11.9 | 11.8 (.7 sec shift) | 13.2 | 11.2 |
| 60 | 18.4 | 18.0 | 17.1 | 17.0 | 18.6 | 16.1 |

## VEHICLE ACCLERATION WITHOUT ELECTRIC MOTOR

| MPH | TIME (SECONDS) | | | | |
|---|---|---|---|---|---|
| 20 | 3.4 | 4.3 | 4.4 | 4.2 | 4.5 |
| 30 | 6.4 | 7.9 (1 sec shift) | 7.9 (.7 sec shift) | 8.1 (.7 sec shift) | 7.1 |
| 40 | 10.9 (.7 sec shift) | 12.0 | 12.0 | 12.4 | 11.8 (.7 sec shift) |
| 50 | 15.5 | 16.5 | 16.3 | 16.5 | 16.3 |
| 60 | 23.8 | 26.0 | 23.5 | 24.6 | 23.3 |

WINDS LESS THAN 6 MPH
TEST DONE ON AN OVAL TRACK IN BOTH DIRECTIONS
TEST WEIGHT 4950 POUNDS

## TABLE V

## SOUND LEVELS

## SAE J 986a DRIVE BY TEST

| | VEHICLE LEFT SIDE DECIBLES | VEHICLE RIGHT SIDE DECIBLES |
|---|---|---|
| RUN 1 | 78 | 78 |
| RUN 2 | 78 | 79 |
| RUN 3 | 79 | 79 |
| RUN 4 | 78 | 78 |

PETRO - ELECTRIC MOTORS, LTD.

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ALTERATIONS AND IMPROVEMENTS MADE TO THE PEM HYBRID DURING THE PERIOD MAY-SEPTEMBER 1974 (Before latest tests) and DURING THE PERIOD OCTOBER-NOVEMBER 1974 (During latest tests)

| CHANGE | REASON |
|---|---|
| **Completed Before Tests** | |
| Plugging Resistor | To reduce time for engine RPM reduction to zero after turn-off. |
| Automatic Idle Resistor Cutout | To achieve high speed idle during first 25 seconds. |
| Re-jet Carburetor | To produce proper reactor temperature at 12" Vacuum, and eliminate "lean hole" without need of second operator to vary choke while driving. |
| Tires - Radial | Replace original equipment tires with Radial Tires on the rear wheels. |
| **Completed During Tests** | |
| Resistor in Field Control Circuit | To improve 100/50V transition, to eliminate wasted armature current discharge. |
| Engine Throttle Override Cable | Re-arrange engine throttle override cable to activate lever arm under hood for convenience of adding dashpot, if desired. |
| Choke and Manifold Vacuum | Utilize new choke countdown and manifold vacuum schedule. |
| Modified Vacuum and EGR | Modified Vacuum and EGR settings in attempt to attain correct battery SOC. This involves putting in a controller that maintained the vacuum at settings other than the original 12". |

[illegible]

TABLE VI b

PETRO - ELECTRIC MOTORS, LTD.

Hybrid Power Train Vehicle

## OPERATING INSTRUCTIONS

### URBAN TEST

SHIFT POINTS*: First ⟷ Second = 18 mph

Second ⟷ Third = 33 mph

CAR PREPARATION :

CHOKE at approximately 0.09" Open and handle in UP position **;

15" VACUUM; No EGR;

Emission Control at 5mV - 26mV***;

Throttle Limiter in place

Field Current ON; Ignition Key ON.

START: Press START Button

COLD START RUN: Countdown

| TIME | OPERATION |
|---|---|
| 3 sec. | 1/2 turn Leaner (clockwise) |
| 10 sec. | 1/2 turn Leaner |
| 19 sec. | 1/2 turn Leaner |
| 30 sec. | 1/2 turn Leaner |
| 60 sec. | { 10" VAC<br>EGR ON |
| 70 sec. | 1/2 turn Leaner |
| 80 sec. | 1/2 turn Leaner |
| 240 sec. | 2-1/2 turns Leaner |

1360 sec. - Throttle Limiter OFF

## HOT START PREPARATION:

15" VACUUM; NO EGR;

CHOKE Enriched 2-1/2 Turns from end of previous run;

Emission Control at 15mV - 26mV;

Throttle Limiter in Place

## HOT START RUN: Countdown

| TIME | OPERATION |
| --- | --- |
| 10 sec. | 10" VAC<br>EGR ON |
| 60 sec. | 2-1/2 turns Leaner |
| 1360 sec. | Throttle Limiter OFF |

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* For Cold Start shift at First - Second at 26 mph and Second - Third at 40 mph for the first 40 seconds. Because of carburetion problem, it is important that engine not be kept in gear below shift points. For Deceleration recommend de-clutching at no less than 35 mph in Third Gear and 20 mph in Second Gear.

** Choke butterfly is set at 11-1/2 turns from fully open position. This can be checked with feeler gauge set at 0.09" and choke dial in 1:30 position.

*** Emission Meter lower limit set so car starts with spark advanced for 5mV. Therefore, for Cold Start lower limit set at 5mV and for Hot Start at 15mV (since reactor will be at approximately 10mV).

CLR:sg
11-1/9898

TABLE VIIa

MASS EMISSIONS
GRAMS PER MILE

| TEST NUMBER | Bag 1 Cold Transient HC | CO | $CO_2$ | NOx | MPG | Bag 2 Hot Stabilized HC | CO | $CO_2$ | NOx | MPG | Bag 3 Hot Transient HC | CO | $CO_2$ | NOx | MPG | Bag 4 Hot Stabilized HC | CO | $CO_2$ | NOx | MPG |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 16-6366, 16-6367 | .80 | 5.24 | 872.0 | .55 | 10.1 | .05 | .64 | 1220.5 | .94 | 7.3 | .50 | 2.58 | 786.7 | .66 | 11.2 | .06 | .83 | 1238.0 | .93 | 7.2 |
| 21-6447, 21-6448 | .88 | 6.50 | 838.1 | .50 | 10.4 | .08 | .64 | 1169.4 | .88 | 7.6 | .71 | 3.63 | 748.8 | .61 | 11.7 | .12 | .58 | 1164.1 | .92 | 7.6 |
| 16-6728 | .99 | 6.74 | 1040.3 | 1.59 | 8.4 | .02 | .36 | 1506.4 | 4.40 | 5.9 | .38 | 2.15 | 994.1 | 2.46 | 8.9 | | | | | |

## TABLE VII b

| TEST NUMBER | MILES | TYPE TEST | WEIGHTED EMISSIONS GRAMS/MILE HC | CO | $CO_2$ | NOx | FUEL ECONOMY MPG | | AVERAGE BATTERY VOLTS | SPECIFIC GRAVITY | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 16-6366, 16-6367 | 15 | FTP | .33 | 2.17 | 1035.6 | .78 | 8.5 | After | 12.58 | 1.235 | Balanced FTP |
| 31 OCT | | | | | | | | Before | 12.57 | 1.230 | |
| | | | | | | | | | +.01 | +.005 | |
| 21-6447, 21-6448 | 15 | FTP | .43 | 2.65 | 984.9 | .74 | 9.0 | After | 12.57 | 1.225 | Balanced FTP |
| 5 NOV | | | | | | | | Before | 12.54 | 1.224 | |
| | | | | | | | | | +.03 | +.001 | |
| 16-6464 6 NOV | 10.225 | HWY | .13 | 1.09 | 485.5 | .6 | 18.2 | After | 12.34 | 1.200 | Unbalanced HWY |
| | | | | | | | | Before | 12.57 | 1.225 | |
| | | | | | | | | | -.23 | -.025 | |
| 16-6693 18 NOV | 10.225 | HWY | .01 | .11 | 569.7 | 1.62 | 15.6 | After | 12.50 | 1.230 | Balanced HWY |
| 16-6694 | 10.225 | HWY | .0 | .10 | 567.5 | 1.56 | 15.6 | Before | 12.44 | 1.231 | |
| | | | | | | | | | +.06 | -.001 | |
| 16-6728 19 NOV | 11.1 | FTP | .32 | 2.16 | 1270.0 | 3.29 | 7.0 | After | 12.60 | 1.244 | Unbalanced FTP |
| | | | | | | | | Before | 12.50 | 1.230 | |
| | | | | | | | | | .10 | .014 | |