73-28 DWP

Evaluation of the Ethyl Corporation Lean Thermal Reactor System

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Emission Control Technology Division
Office of Air & Water Programs
Environmental Protection Agency

Background

The Ethyl Corporation has had a long term development program on emission control systems utilizing lean thermal reactors. Because their system represents a thoroughly tested example of this type of control technique the Office of Air and Water Programs contacted the Ethyl Corporation and requested an evaluation of their system. A test program was undertaken by the Test and Evaluation Branch.

Device Description

This system incorporated lean carburetion, EGR, and thermal reactors. A more detailed description, prepared by Ethyl, is attached.

Test Program

A 1972 Fury III with a 360 CID engine and the Ethyl lean thermal reactor system was tested. Three tests were conducted in accordance with the 1975 Federal Test Procedure (FTP) as described in the November 15, 1972, Federal Register. All test work was conducted at 4500 pounds inertia weight.

Results

The results from the tests are reported in the attached table. These results demonstrate that emission levels well below 1975 interim standards can be achieved with this sytem. For comparative purposes an average 1972 FTP result was calculated using results from the first two bags of the reported 1975 test work. Comparison of this data with 1973 certification emissions levels and fuel economy are shown. This vehicle demonstrated significantly better emissions and fuel economy than a similar 1973 certification vehicle. General impression of vehicle driveability was good.

Conclusions

Ethyl Corporation's lean thermal reactor system installed on a 1972 Fury (360 CID engine) demonstrated the potential for achieving emission levels well below 1975 interim standards. This vehicle as equipped with Ethyl's system also demonstrated good fuel economy and driveability and was lead insensitive. The vehicle tested did not, however, meet either the statutory 1975 or 1976 standards.

Emissions and Fuel Economy
1975 FTP

	HC gm/mi	CO gm/mi	NOx gm/mi	CO_2 gm/mi	Fuel Consumption mpg
Test 1	.78	5.93	1.42	756.49	11.23
Test 2	.78	5.51	1.30	769.51	11.05
Test 3	.87	5.77	1.42	746.80	11.96
Average	.81	5.74	1.38	757.60	11.41
1975 Interim Standards	1.5	15.0	3.1	---	---
1976 Interim Standards	0.4	3.4	0.40	---	---

Emissions and Fuel Economy
1972 FTP

	HC gm/mi	CO gm/mi	NOx gm/mi	CO_2 gm/mi	Fuel Consumption mpg
Avg. 3 tests	1.06	7.07	1.42	755.91	11.23
1973 Ce[illegible] Results	2.6	38.0	2.4	---	9.7

APPENDIX

LEAN REACTOR SYSTEMS

Carburetion, Mixture and Air Heating, EGR, Ignition Advance, and Automatic Starting Sequence Device

Carburetion

The effectiveness of the lean reactor system depends primarily on improved carburetion. The advantages of lean operation have long been known; but, with conventional carburetion, problems can limit its usefulness. Problems in making conventional engines lean are that some cylinders may become much leaner than others, or mixtures within the individual cylinders may vary. By causing combustion to be poor in some cylinders, this can produce an increase in hydrocarbon emissions rather than the expected decrease. Driveability difficulties also can result from poor combustion in the excessively lean cylinders. Both of these problems tend to increase when exhaust gas is recirculated for reduction of NO_x. Another problem is that, when an engine is made only moderately lean, NO_x increases. However, this increase occurs only until air-fuel ratios of 15-16:1 have been reached and, as the mixture is made leaner beyond this point, NO_x decreases. Earlier research showed that problems of lean mixtures could be overcome and the limits of satisfactory lean operation extended if the air-fuel mixture was very well mixed and evenly divided among the cylinders. The 3-venturi carburetor was developed to provide a high degree of atomization and mixing, along with close-tolerance metering of the air-fuel mixture. This carburetor utilizes high air velocities for mixing. Other design characteristics also help. These include the geometry of the fuel nozzle and the use of perforations in the primary throttle plate through which the mixture passes under some conditions. Also, a mixing tube extends into the intake manifold beneath the primary throttle.

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

Mixture and Air Heating

Quick warm-up is a critical factor in advanced emission control systems. Several systems are used in the lean reactor to improve performance and emissions during the first few minutes after starting. As mentioned earlier, choking is carefully regulated and the idle air-fuel mixture is temperature compensated. In addition, the intake manifold is modified in the hot-spot section beneath the carburetor throats to transfer heat rapidly from the exhaust gas side of the manifold crossover to the intake side. This provides more rapid vaporization of fuel on the cold start. This modification consists of discs of finned stainless steel that replace portions of the normal cast iron structure in the hot-spot area. A crossover heat control valve directs exhaust gas from one side of the engine through the crossover and out the other side during the cold-start period. After warm-up, this valve opens and the exhaust gas bypasses the hot-spot area. Carburetor air also is preheated rapidly by the use of a muff-type preheater installed at one reactor outlet. The conventional temperature control valve in the air cleaner opens after warm-up to maintain carburetor air at the normal temperature.

Exhaust Gas Recirculation System

A modulating EGR system is used to vary the amount of EGR used during different driving modes. The primary signal used to modulate EGR is venturi vacuum--a measure of engine airflow. This vacuum signal operates a vacuum motor and, in turn, a contoured cam that positions a pintle valve located between the exhaust source and the intake manifold. This basic system is subject to additional controls that actuate a solenoid valve that either blocks or opens the vacuum line to the vacuum motor. These controls are shown in Figure A-1. A temperature-sensing switch in the air cleaner blocks out EGR until carburetor air temperature exceeds 60°F, at which time the engine can tolerate the dilution. This overcomes cold-start problems and drive-away deficiencies at low temperatures. Similarly, to prevent problems caused by charge dilution from exhaust gas immediately after the engine starts, a time delay in the circuit prevents the onset of EGR until 40 seconds after the engine starts. EGR also is shut off during idle and heavy deceleration by a throttle switch that senses the closed throttle position. Under full-throttle conditions, EGR is shut off by a manifold vacuum switch as a safety measure to permit full power development. A speed switch also interrupts EGR use at speeds above 60-65 mph. Interruption of EGR at high speeds causes reactor temperatures to decrease by about 200°F. Thus, this control permits the use of high reactor temperatures at moderate speeds without excessive temperatures at extremely high speeds, and contributes both to good performance of the system and durability of the reactors.

Ignition Advance System

Figure A-2 shows the system used to control distributor vacuum advance. A solenoid valve opens or closes the vacuum line to the vacuum advance unit and permits vacuum advance under some operating conditions but not under others. EGR and ignition timing are related to each other to maintain good driveability and emission control. Under stabilized engine operating temperatures, no vacuum advance is applied until EGR has begun to flow. Then the solenoid opens and vacuum advance is applied. Spark advance coming on at this point offsets the sluggishness of EGR. However, when the engine is cold and EGR has not yet become operative, vacuum advance is desirable for good engine starting and performance. Thus, temperature overrides are used to apply vacuum advance regardless of EGR until the temperatures of both the engine block and the air cleaner exceed 60°F. Similarly, to prevent overheat problems, vacuum advance is applied if engine coolant temperature exceeds 220°F. Another circuit maintains vacuum advance at high speeds regardless of EGR. Characteristics of the vacuum advance have been modified to provide greater-than-normal advance when manifold vacuum is low. This is done to compensate for the low manifold vacuums that accompany lean mixtures and EGR. The distributor also incorporates a solenoid that can retard ignition timing 10°. This solenoid is actuated for a few seconds after starting and is controlled by the automatic starting sequence device (ASD), as described below.

Automatic Starting Sequence Device

To obtain low emissions, it is essential that an engine warm up quickly with minimum choking. In some experimental cars, momentary use (about 10 seconds) is made of higher speeds, retarded timing and greater throttle opening during initial starting to hasten warm-up. Retarded timing has three effects. One is to reduce hydrocarbon emissions. A second is to increase the temperature of the exhaust gas. The third is to reduce engine power output, which permits a larger throttle opening for a given engine speed. Figure A-3 shows how these factors have been combined into a simple, automatic starting sequence device. Physically this device consists of a small vacuum-operated piston mounted near the carburetor. Vacuum is applied through a solenoid valve. When the engine first starts, the solenoid opens and vacuum is applied to the piston. The piston advances the throttle in a manner similar to the conventional choke-operated high-speed idle. At the same time, the piston closes electrical contacts to actuate the solenoid that retards the distributor about 10° and blocks off vacuum advance. Thus the device causes a high idle speed with a heavily retarded spark for about 10 seconds after starting. Then the system disengages and will not reindex to repeat the cycle unless the ignition switch has been turned off for a few seconds. Thus it does not complicate operation in the event of an engine stall.

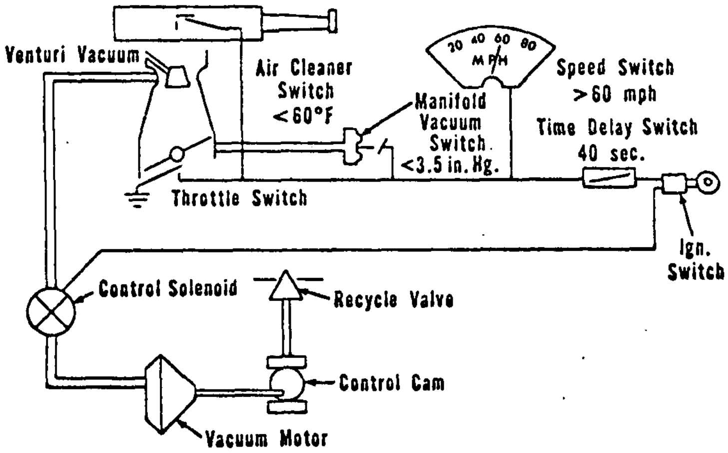

Figure A-1. Exhaust Gas Recycle System

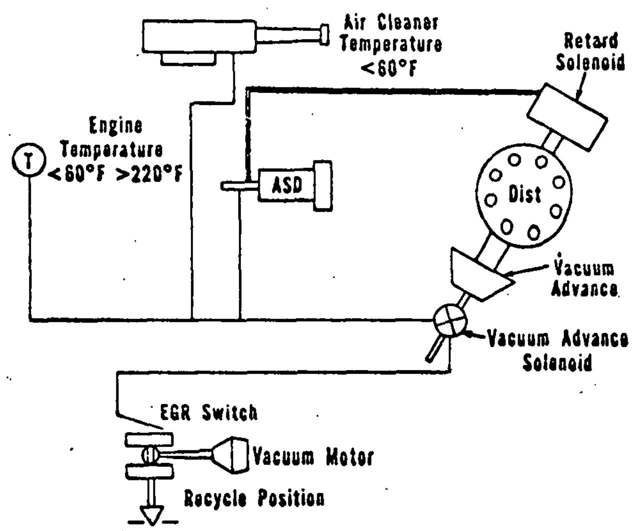

Figure A-2. Modified Ignition System

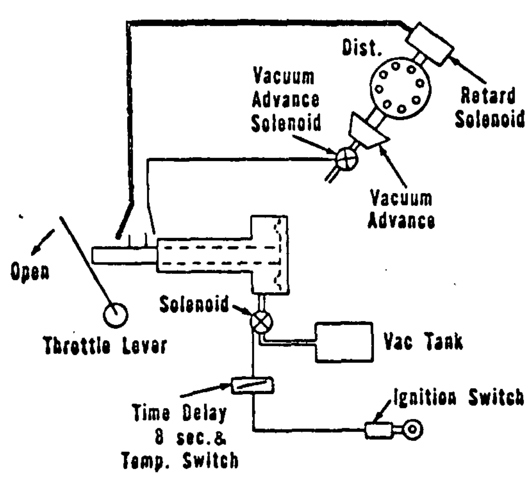

Figure A-3. Automatic Start Device (ASD)