76-5 AB

Evaluation of the Ethyl Lean Reactor System Applied to a Dodge Coronet

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Technology Assessment and Evaluation Branch
Emission Control Technology Division
Office of Mobile Source Air Pollution Control
Environmental Protection Agency

Background

For many years, Ethyl Corporation engineers have conducted research into engine operation at lean air-fuel ratios. They were interested in lean-mixture combustion because of the inherently low emissions and good fuel economy that are possible without catalytic aftertreatment with a properly controlled lean engine. Some of their recent research efforts have been directed toward a demonstration of the potential of lean-mixture control techniques to meet emissions standards.

The Emission Control Technology Division (ECTD) recently tested (Report 75-23) an Ethyl lean burn car equipped with a Turbulent Flow Manifold (TFM). The system was installed on a BMW 2002. This vehicle met the 1975 Federal emission standards and gave excellent fuel economy.

Ethyl has also done similar work on full sized vehicles. They have achieved significant reductions in emissions on these vehicles and one vehicle has completed mileage accumulation. ECTD, consistent with its continuing interest in the evaluation of advanced automotive technology, requested a vehicle for testing. Ethyl Corporation provided a Dodge Coronet equipped with their TFM induction system and exhaust after-treatment.

The Environmental Protection Agency receives information about many systems which appear to offer potential for emissions reduction or improvement in fuel economy compared to conventional engines and vehicles. EPA's Emission Control Technology Division is interested in evaluating all such systems, because of the obvious benefits to the Nation from the identification of systems that can reduce emissions, improve economy, or both. EPA invites developers of such systems to provide to the EPA complete technical data on the system's principle of operation, together with available test data on the system. In those cases in which review by EPA technical staff suggests that the data available show promise for the system, attempts are made to schedule tests at the EPA Emissions Laboratory at Ann Arbor, Michigan. The results of all such tests are set forth in a series of Technology Assessment and Evaluation Reports, of which this report is one.

The conclusions drawn from the EPA evaluation tests are of limited applicability. A complete evaluation of the effectiveness of an emission control system in achieving improvements on the different types of vehicles that are in actual use requires a much larger sample of test vehicles that is economically feasible in the evaluation test projects conducted by EPA. For promising systems it is necessary that more extensive test programs be carried out.

The conclusions from this EPA evaluation test can be considered to be quantitatively valid only for the specific test car used. However, it is reasonable to extrapolate the results from the EPA test to other types of vehicles in a directional or qualitative manner, i.e., to suggest that similar results are likely to be achieved on other types of vehicles.

Vehicle Description

The vehicle tested was a Dodge Coronet with a 360 cubic inch (5899 cc), V-8 engine and a 3-speed automatic transmission. The standard induction system was replaced by an Ethyl TFM. Thermal reactors were added for exhaust after-treatment. (The vehicle is described in detail on the following page.)

The Ethyl Lean Reactor System (LRS) is a lean combustion system with exhaust after-treatment. The intake manifold incorporates a number of modifications to improve the homogeneity of the fuel-air mixture without fuel economy or performance penalties. The manifold (Figure 1) is a Dodge intake manifold modified to improve the quality of the fuel-air mixture. The original carburetor was replaced by a unit with an integral choke. Exhaust port liners were installed in the heads and lean thermal reactor manifolds replaced the original exhaust manifolds.

The essential features of the TFM are the long mixing tube below the primary venturi, the change of flow direction in the mixing box, and the secondary venturi bypass. The long mixing tube allows the fuel-air mixture downstream of the throttle to become more uniform. Changing the flow direction increases turbulence which improves the mixture quality and causes large fuel droplets to fall onto the mixing box floor, where they are vaporized before reentering the stream. The secondary flow bypasses the mixing box in order to minimize pumping losses, thus minimizing losses in volumetric efficiency.

Ethyl had previously installed their TFM on similar full sized vehicles. Their test results showed that the major result of the addition of port liners and thermal reactors was to lower hydrocarbons. This permitted additional exhaust gas recirculation to achieve lower NOx levels while simultaneously improving fuel economy by additional spark advance.

In addition the vehicle was equipped with a particulate trap (Figure 2) to remove lead particles from the vehicle exhaust. Large particles are removed by a vortex inertia trap. Small particles are agglomerated to become large particles which are then inertially separated. EPA did not test the effectiveness of this particulate trap.

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1974 Dodge Coronet
Emission control system - Ethyl Lean Mixture System with after-treatment

Engine

type	4 stroke Otto Cycle, V-8
bore x stroke	4.00 x 3.58 in./101.6 x 90.9 mm
displacement	360 cu in./5899 cc
compression ratio	8.6:1
maximum power @ rpm	not available
fuel metering	single 4 barrel carburetor
fuel requirement	regular leaded (per Ethyl Corporation) tested with 100 RON leaded Indolene 30

Drive Train

transmission type	3 speed automatic
final drive ratio	2.71:1

Chassis

type	unitized body/frame, front engine, rear wheel drive
tire size	FR 78 x 14
curb weight	not available
inertia weight	4500 pounds
passenger capacity	6

Emission Control System

basic type	lean combustion (mixture) system - (Turbulent Flow Manifold) exhaust gas recirculation exhaust port liners lean thermal reactor particulate traps
distributor	dual diaphram distributor advance unit
particulate trap	tangential anchored - vortex trap
durability accumulated on system .	52,000 miles

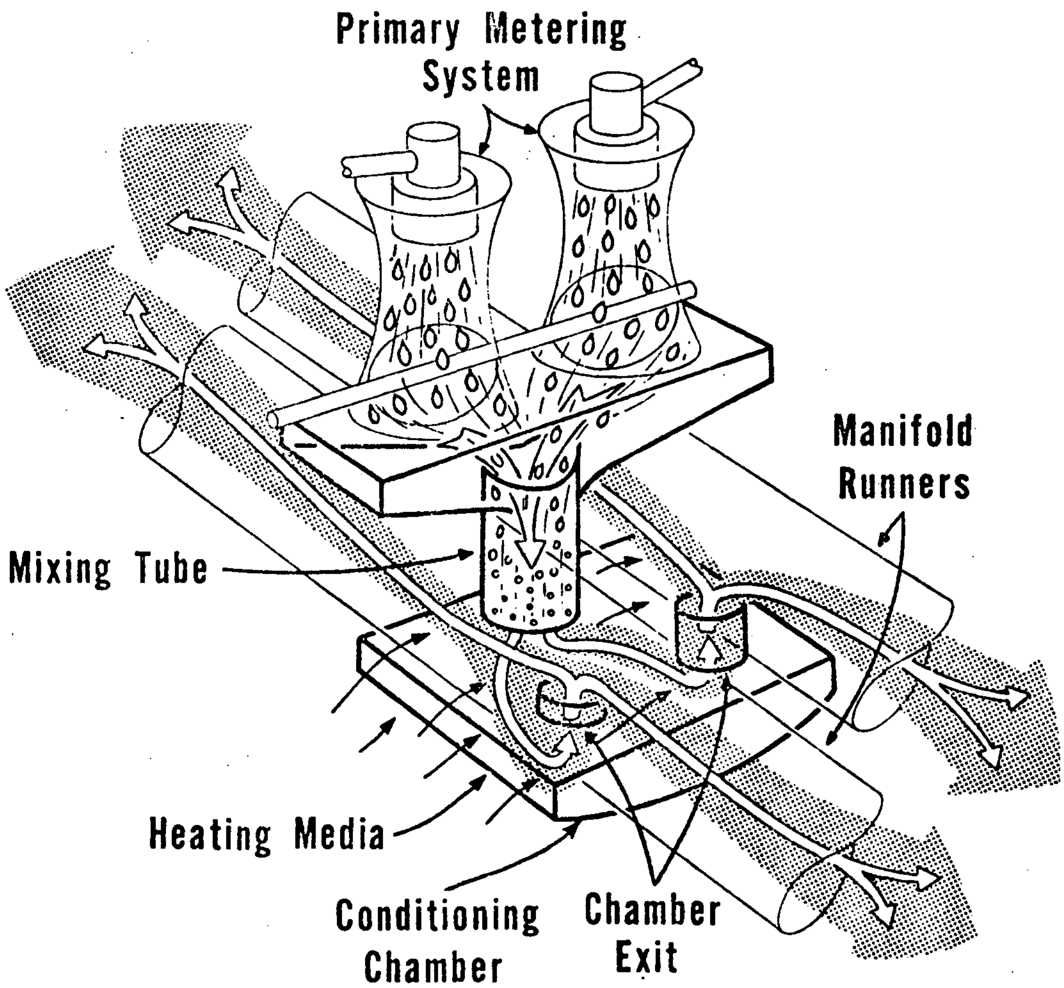

Figure 1. Turbulent Flow Manifold

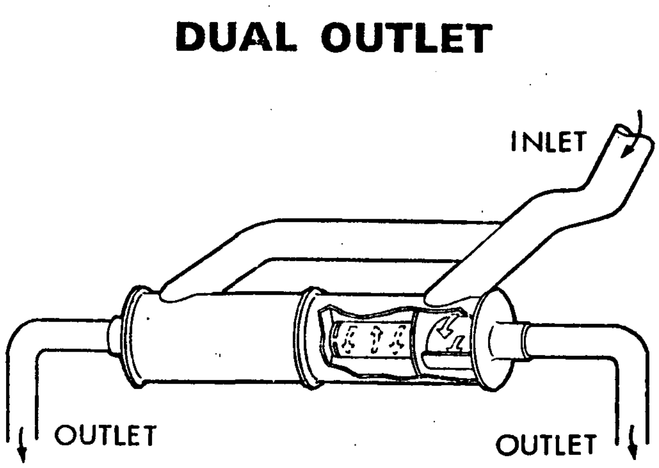

Figure 2. Tangential Anchored-Vortex Traps

Test Procedure

Exhaust emissions tests were conducted according to the 1975 Federal Test Procedure ('75 FTP), described in the Federal Register of November 15, 1972 except that no evaporative emissions tests were conducted. Additional tests included the EPA Highway Cycle and steady state emissions test. All tests were conducted using an inertia weight of 4500 pounds (2041 kg) with a road load setting of 12.7 horsepower (9.5 kW) at 50 miles per hour (80.5 km/hr).

For this vehicle, Ethyl specified a regular gasoline, basing this requirement on their own chassis dynamometer octane rating of 91 Research Octane Number (RON) for leaded fuel and 93 RON for unleaded fuel. The fuel used for the tests reported herein was Indolene 30, a standard leaded (3.0 gm/gal) test fuel of 100 RON.

At the conclusion of the gaseous emissions tests the vehicle was tested for sulfate emissions using the EPA sulfate procedures, which are described in the Appendix.

Test Results

Exhaust emissions data, summarized below, showed that the Ethyl test car, using the LRS, achieved the levels of the 1975-76 Federal and California standards at 52,000 miles. Detailed test results appear in the appendix to this report.

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

	HC	CO	NOx	Fuel Economy (Fuel Consumption)
average of 2 tests	.38 (.24)	5.34 (3.32)	1.64 (1.02)	12.5 miles/gal (18.8 litres/100 km)
1975-76 Federal Standards	1.5	15.0	3.1	
1975-76 California Standards	.9	9.0	2.0	

On EPA Highway Cycle the results were:

EPA Highway Cycle Mass Emissions
grams per mile
(grams per kilometre

	HC	CO	NOx	Fuel Economy (Fuel Consumption)
average of 3 tests	.08	1.69	2.85	21.4 miles/gal
	(.05)	(1.05)	(1.77)	(11.0 litres/100 km)

Steady State fuel economy results were:

Speed mph (km/hr)	Fuel Economy miles/gal	(Fuel Consumption) litres/100 km
15 (24.1)	16.9	(13.9)
30 (48.3)	22.1	(10.6)
45 (72.4)	25.7	(9.2)
60 (96.6)	20.8	(11.3)

Comparison of the test vehicle's combined city/highway fuel economy with certification results for 1976 vehicles of the same inertia weight (4500 pounds) showed that there was no fuel penalty.

	Combined City/Highway	
	Fuel Economy mpg	Fuel Consumption litres/100 km
Ethyl Car 360 CID	15.4	(15.3)
Avg. 1975 4500 lb. vehicle	14.6	(16.1)
Avg. 1976 4500 lb. vehicle*	15.7	(15.0)
Avg. 1976 4500 lb. vehicle*	14.2	(16.6)
Best 1976 4500 lb. vehicle	16.1	(14.6)

* Similar engine and meeting 1976 California standards

$$MPG_{combined} = \frac{1}{\frac{.55}{MPG_{urban}} + \frac{.45}{MPG_{highway}}}$$

In calculating city/highway combined fuel economy, the urban fuel economy is weighted 55% and the highway fuel economy is weighted 45% to account for the 55/45 ratio of urban to rural mileage accumulation.

Emissions of HC, CO, NOx and sulfates are listed in the appendix. For the sulfate tests the test fuel used was Indolene HO (clear) with a sulfur content of .03 weight percent. The tests showed sulfate emissions of about 7 mgpm which is slightly higher than those usually found for other non-catalyst cars (5 mgpm or less). The first test showed sulfate emissions over the FTP to be 17.6 mgpm, an exceptionally high level. It should be noted that the car ran on leaded fuel before being sent to EPA. Also, Ethyl reported the lead trap was full of lead salts, making it possible that lead particulates from the trap could be emitted. It is known that lead compounds interfere with the barium chloranilate method used by EPA. It is therefore possible that this interference may explain the higher than expected emissions of sulfates especially in the initial tests, when more lead may have been emitted. In later tests sulfate emissions were about 5 mgpm. Ethyl personnel analyzed two of the EPA filters by the iodine titration method which is not affected by lead compounds, and found about 20 micrograms of sulfate, which corresponds to an emission rate of about 2 mgpm. The vehicle was tested with the higher (10% of road load) used for air conditioned vehicles.

Vehicle driveability was acceptable and no problems were encountered. There were no vehicle starting problems.

Conclusions

The Ethyl Dodge Coronet equipped with the Turbulent Flow Manifold and Lean Reactor System met the emission levels required by 1975 Federal and California standards at high mileage. There was no fuel economy penalty for this technique relative to typical 1976 vehicles of the same weight class.

Table A-1
'75 FTP Mass Emissions
grams per mile

	Bag 1 Cold Transient					Bag 2 Hot Stabilized					Bag 3 Hot Transient				
Test Number	HC	CO	CO_2	NOx	Fuel Economy MPG	HC	CO	CO_2	NOx	Fuel Economy MPG	HC	CO	CO_2	NOx	Fuel Economy MPG
76-2405	.96	11.35	730	2.21	11.8	.17	3.09	723	1.52	12.2	.33	4.67	579	1.89	15.1
76-2407	.86	12.74	755	1.97	11.4	.17	3.11	751	1.35	11.7	.42	4.41	598	1.49	14.6

Table A-2
'75 FTP Composite Mass Emissions
grams per mile

Test Number	HC	CO	CO_2	NOx	Fuel Economy MPG
76-2405	.38	5.22	685	1.77	12.8
76-2407	.38	5.45	710	1.51	12.3

Table A-3
EPA Highway Cycle Mass Emissions
grams per mile

Test Number	HC	CO	CO_2	NOx	Fuel Economy MPG
76-2405	.07	1.71	425	2.76	20.7
76-2458	.08	1.69	404	2.97	21.8
76-2459	.08	1.68	408	2.83	21.6

Table A-4
Steady State Mass Emissions
grams per mile

Test Number	Speed MPH	HC	CO	CO_2	NOx	Fuel Economy MPG
76-2406*	Idle Neutral	.07	.63	118	.04	.81
76-2408*	Idle Drive	.11	.73	115	.04	.79
76-2409	15	.23	2.67	519	.24	16.9
76-2411	30	.09	1.34	400	.43	22.1
76-2412	45	.29	3.15	336	4.95	25.9
76-2456	45	.34	3.41	340	4.38	25.6
76-2413	60	.06	2.15	427	3.61	20.6
76-2457	60	.07	2.15	417	4.19	21.1

* grams per minute/gallons per hour

Ethyl Lean Reactor System

Procedures used to Measure Sulfate Emissions

1. The leaded fuel was drained from the test vehicle. The vehicle was refueled with Indolene HO gasoline containing 0.017% sulfur by weight. The vehicle then returned to Ethyl for checkout thereby accumulating about 100 miles on this fuel.

2. The vehicle returned and the fuel was drained from the vehicle. The vehicle was refueled with Indolene HO gasoline doped to contain .030% sulfur by weight. This fuel was used throughout the sulfate testing.

3. The vehicle was prepped by driving on the EPA vehicle preparation route and over the LA-4 cycle. The road load was set to include an air conditioning load.

4. The following sequence of test cycles was used to measure sulfate emissions.

   a) Cold start 75 FTP
   b) Two hot sulfate cycles
   c) One EPA Highway Driving Cycle
   d) Two hot sulfate cycles.

   This sequence was run on two consecutive days. Four additional sulfate cycles were run after the last sequence.

5. The barium chloranilate procedure was used to determine the concentration of sulfates in the exhaust.

Sulfate Procedure Emissions
Average Emissions
grams per mile

Test Type	HC	CO	CO_2	NOx	Fuel Economy MPG	H_2SO_4*	% Conversion
75 FTP	.36	6.88	737	1.80	11.8	17.6	7.6
Highway	.06	1.43	438	2.48	20.1	6.2	4.8
Sulfate Cycle	.10	2.89	518	1.83	17.0	5.9	3.8

* Milligrams per mile

Mileage accumulation done with leaded fuel. Vehicle is equipped with a lead particulate trap. EPA sulfate test procedures were developed for unleaded fuel. There may be lead interference causing the results to be high.