Evaluation of the Ethyl Turbulent Flow Manifold Lean Mixture Induction System as Applied to a BMW Two-Litre Automobile

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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 with a properly controlled lean engine. Some of their recent research efforts have been to demonstrate the potential of lean-mixture control techniques to meet the future emissions standards of the European Economic Community.

Part of the recent work at Ethyl has been with vehicles that use small high-performance engines, on which significant reductions in emissions have been achieved. The Emission Control Technology Division, consistent with its continuing interest in the evaluation of advanced automotive emission control technology, requested a vehicle for testing, and a BMW 2002, equipped with Ethyl's Turbulent Flow Manifold induction system, was made available.

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 than 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 BMW 2002 with a four cylinder, 121.3 cubic inch (1988 cc), overhead cam engine and a 3-speed automatic transmission. The standard induction system was replaced by an Ethyl Turbulent Flow Manifold (TFM). (The car is described in detail on the following page.)

The Ethyl TFM is a lean combustion system. The carburetor and intake manifold incorporate 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 BMW 2002 intake manifold modified to improve the quality of the fuel-air mixture. The original Solex carburetor was replaced by a Holley carburetor (Model 5200) that was re calibrated to deliver the proper lean fuel-air mixture. The primary section was modified to improve fuel atomization at low air flow rates.

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.

On this vehicle, Ethyl's efforts were directed toward reducing the vehicle's HC and CO emissions without a fuel economy or performance penalty. NOx levels were to be maintained near the levels of the original vehicle.

The techniques used by Ethyl have resulted in reduced pollutant emissions (except NOx) without exhaust gas recirculation (EGR) or air injection. (The stock 1973 BMW 2002 is equipped with EGR; the 1975 models have EGR, air injection and a rich thermal reactor).

Test Procedures

Exhaust emission 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. In addition the vehicle was tested for emissions and fuel economy using the EPA Highway Cycle. Since the current model of this vehicle has increased in weight, the testing was conducted at both weights.

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1973 BMW 2002
Emission control system - Ethyl Lean Mixture System

Engine

type	4 stroke Otto cycle, SOHC, 4 cyl. in-line
bore x stroke	3.50 x 3.15 in./88.9 x 80 mm
displacement	121.3 CID/1988 cc
compression ratio	8.5:1
maximum power @ rpm	103 bhp (SAE)/76.8 kW @ 5200 RPM*
fuel metering	single 2 barrel carburetor
fuel requirement	regular leaded (per Ethyl Corp.) tested with 100 RON leaded Indolene 30

Drive Train

transmission type	3 speed automatic
final drive ratio	3.64:1

Chassis

type	unitized body/frame, front engine, rear wheel drive
tire size	165 HR 13
curb weight	2285 lbs./1036 kg
inertia weight	2500/2750 pounds
passenger capacity	4

Emission Control System

basic type	lean combustion (mixture) system - (Turbulent Flow Manifold)
distributor	standard BMW unit, mechanical advance only
*durability accumulated on system	3000 miles
	31,000 miles on vehicle and engi

* Information supplied by Ethyl Corporation.

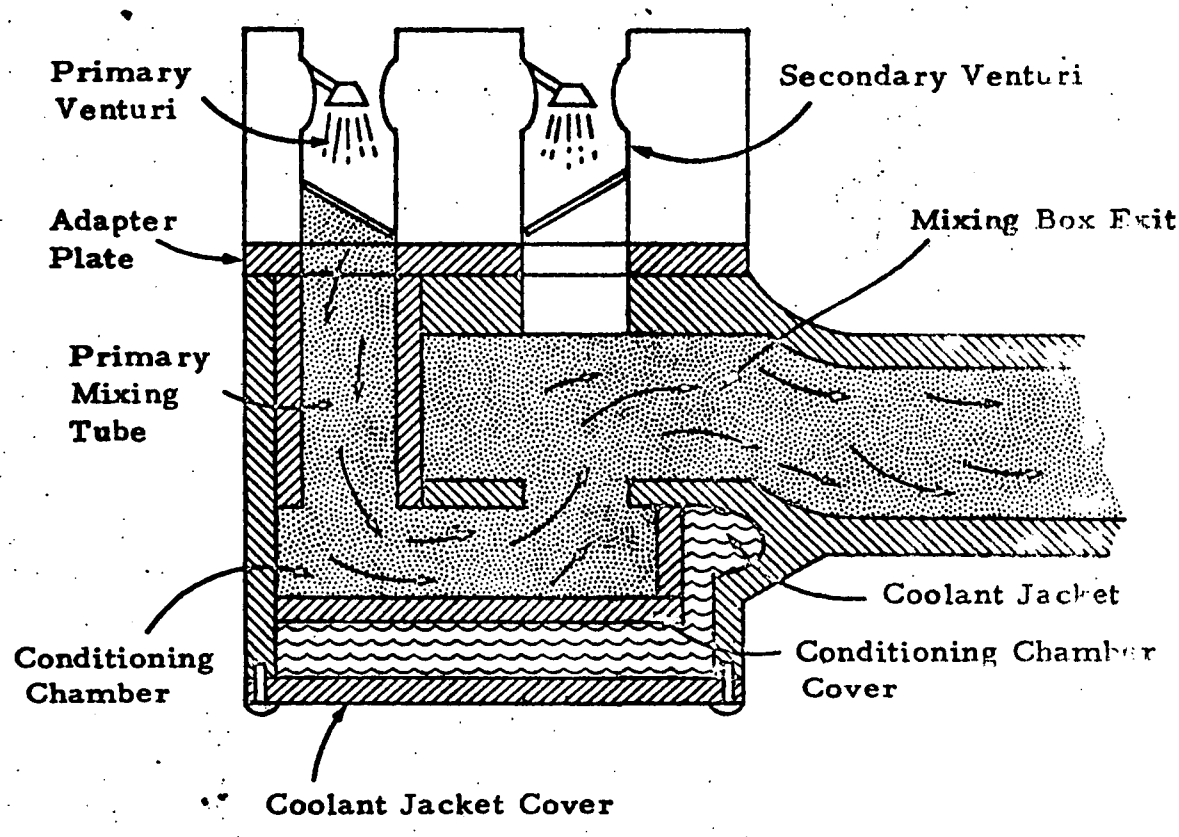

Figure 1. Turbulent Flow Intake Manifold for BMW

Ethyl's development and testing on this vehicle was conducted using a test inertia weight (IW) of 2500 pounds (1134 kg). However, the 1975 BMW 2002 with automatic transmission was certified at 2750 pounds (1247 kg). Therefore, to allow comparison of the EPA test results with Ethyl's data and with certification results, the vehicle was tested at both weights. To permit comparison with Ethyl's results, tests were conducted using an IW of 2500 pounds with a road load setting of 9.4 horsepower (7.0 kW) at 50 miles per hour (80.5 km/hr). And, to permit comparison with certification results, tests were conducted using an IW of 2750 pounds with a road load setting of 9.9 horsepower (7.4 kW) at 50 miles per hour. For comparison with certification data on the baseline (stock 1973) car, mass emissions have also been calculated by the 1972 FTP from the two tests at 2500 lbs.

Two '75 FTP's and two EPA Highway Cycles were run at each inertia weight. No calibration changes were made to the vehicle to adjust for these different vehicle test weights.

For this vehicle, Ethyl specified a regular leaded gasoline, basing this requirement on their own chassis dynamometer octane rating of 92 Research Octane Number (RON). The fuel used for the tests reported herein was Indolene 30, a standard leaded (3.0 gm/gal) test fuel of 100 RON.

Test Results

Exhaust emissions data, summarized below, showed that the Ethyl test car, using the TFM, achieved the levels of the 1975 Federal emissions standards at low mileage, but did not meet the stricter California standards. 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)
Ethyl BMW 2002 2500 pounds Average of 2 tests	1.08 (.67)	6.20 (3.85)	2.85 (1.77)	25.1 miles/gal (9.4 litres/100 km)
Ethyl BMW 2002 2750 pounds Average of 2 tests	1.20 (.75)	8.57 (5.32)	2.79 (1.73)	24.6 miles/gal (9.6 litres/100 km)
Certification Values 1975 BMW 2002 2750 lbs. Automatic Transmission	.26 (.16)	6.60 (4.10)	1.11 (.69)	20.4 miles/gal (11.6 litres/100 km)
1975 Federal Standards	1.5	15.0	3.1	
1975 California Standards	0.9	9.0	2.0	

On the EPA Highway Cycle the results were:

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

	HC	CO	NOx	Fuel Economy (Fuel Consumption)
Ethyl BMW 2002 2500 pounds Average of 2 tests	.33 (.21)	3.33 (2.07)	2.07 (1.28)	30.8 miles/gal (7.6 litres/100 km)
Ethyl BMW 2002 2750 pounds Average of 2 tests	.41 (.25)	3.47 (2.15)	2.32 (1.44)	30.9 miles/gal (7.6 litres/100 km)
Certification Values 1975 BMW 2002 2750 lbs., Automatic Transmission	.02 (.01)	.95 (.59)	1.16 (.72)	28.9 miles/gal (8.1 litres/100 km)

A comparison of fuel economy values shows that the Ethyl BMW (at 2750 lbs.) delivered better fuel economy than the '75 BMW tested for certification. The Ethyl car's fuel economy was 21% better on the '75 FTP and 7% better on the Highway Cycle. Not only was the Ethyl BMW better in fuel economy that the '75 BMW, it was better than all other '75 models in the 2750 pound IW class.

To compare the Ethyl car with a "baseline" car, '72 FTP mass emissions were calculated using the data from the two 75 FTP's that were run at 2500 lbs. inertia weight. The "baseline" car was considered to be the car tested for 1973 model year certification. (The 1972 FTP was used for certification in model years 1972 through 1974). Results are summarized below.

1972 FTP Mass Emissions
grams per mile
(grams per kilometre)

	HC	CO	NOx	Fuel Economy (Fuel Consumption)
Ethyl BMW 2002 2500 pounds average of 2 tests	1.29 (.80)	9.37 (5.82)	2.90 (1.80)	24.0 miles/gal (9.8 litres/100 km)
Certification Values 1973 BMW 2002 2500 lbs., Automatic Transmission	2.1 (1.3)	27 (17)	1.5 (.9)	21.8 miles/gal (10.8 litres/100 km)

Emissions of HC and CO from the Ethyl car were considerably lower than those from the '73 certification BMW, but NOx emissions were 93% higher. Fuel economy of the Ethyl car was 10% better.

Certain driveability problems were noted on the Ethyl BMW. When the vehicle was driven on the road as part of the test preparation and to check driveability, moderate surge was evident. However during a similar check at the conclusion of testing, only slight surge was noted. During three of the four cold start 75 FTP's the vehicle stalled. Investigating the surge problem after this EPA test program, Ethyl engineers found that the surge was due to liquid fuel which collected in vacuum supply passages in the special carburetor adapter plate, and then was pulled into the air stream at sporadic intervals, causing a surge in engine power. A simple modification to the adapter plate provides ventilation to those passages, preventing a buildup of fuel. Subsequent driveability evaluations by EPA engineers confirmed that the earlier surge problem was solved.

Conclusions

The Ethyl BMW equipped with the Turbulent Flow Manifold met the emissions levels required by the 1975 Federal Standards with a minimum of emission control devices. The fuel economy of the Ethyl BMW was improved over not only the current (1975 model) BMW 2002 and the baseline (1973 model) vehicle, but also all other 1975 models in the 2750 pound IW class.

The Ethyl BMW has shown that a car without a catalyst can meet the 1975 Federal standards and deliver excellent fuel economy. It is the technical judgment of EPA personnel that the car has demonstrated low enough emissions from the engine to permit it to meet emission levels of 0.41 HC, 3.4 CO, and 2.0 NOx with the addition of a catalyst or other exhaust aftertreatment device to the system. Although the spark timing schedule of the engine is advanced compared to the stock schedule, EPA personnel feel that the car can probably be operated with customer acceptability on 91 RON fuel, leaded or unleaded (BMW specifies either fuel for the car), since neither the compression ratio (8.5:1) nor the combustion chamber was changed. We feel that the use of an oxidizing catalytic converter or a lean thermal reactor in conjunction with the TFM would be a fruitful area of investigation, since such combinations appear to have potential for further reductions in HC and CO emissions and possibly fuel economy gains as well. Proportional EGR could be used to reduce NOx formation without affecting fuel economy.

Ethyl Corporation personnel are continuing development of the TFM system; it is presently installed on intermediate and full size cars in addition to the BMW. The EPA plans to test those cars in the near future.

Table A-1

'75 FTP Mass Emissions
grams per mile

TEST NUMBER	INERTIA WEIGHT	BAG 1 COLD TRANSIENT					BAG 2 HOT STABILIZED					BAG 3 HOT TRANSIENT				
		HC	CO	CO_2	NOx	FUEL ECONOMY MPG	HC	CO	CO_2	NOx	FUEL ECONOMY MPG	HC	CO	CO_2	NOx	FUEL ECONOMY MPG
19-8245	2500	1.68	17.41	361	3.35	22.5	1.00	3.90	331	2.26	26.1	.85	3.97	313	3.09	27.6
16-8298	2500	1.55	13.71	372	3.66	22.3	.96	3.47	347	2.42	25.0	.86	3.90	329	3.53	26.3
19-8278	2750	1.88	21.25	371	3.45	21.6	1.04	4.11	346	2.35	24.9	.95	5.10	328	3.30	26.2
16-8325	2750	1.92	23.03	367	3.22	21.7	1.02	5.24	342	2.32	25.1	1.02	6.43	320	3.18	26.6

Table Ib

'75 FTP Composite Mass Emissions
grams per mile

TEST NUMBER	INERTIA WEIGHT	HC	CO	CO_2	NOx	FUEL ECONOMY MPG
19-8245	2500	1.10	6.70	332	2.71	25.6
16-8298	2500	1.06	5.70	347	2.98	24.7
19-8278	2750	1.19	7.91	346	2.84	24.5
16-8325	2750	1.21	9.22	341	2.74	24.7

Table A-2

EPA Highway Cycle Mass Emissions
grams per mile

TEST NUMBER	INERTIA WEIGHT	HC	CO	CO_2	NOx	FUEL ECONOMY MPG
19-8245	2500	.33	3.09	273	1.95	31.8
16-8298	2500	.33	3.56	290	2.18	29.9
19-8278	2750	.39	3.50	286	2.13	30.3
16-8325	2750	.43	3.43	275	2.50	31.5