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Exhaust Emissions and Fuel Economy from a Volvo Three-Way Catalyst Prototype Vehicle

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

Background

In its continuing interest to keep abreast of technological developments in the area of emission controls, the Environmental Protection Agency requested Volvo of America Corporation to allow EPA to perform emissions testing on a prototype Volvo fitted with their three-way-catalyst system (TWC). Volvo agreed and sent a vehicle from Sweden which arrived in Ann Arbor on November 8, 1974. The catalyst had 4000 miles accumulated on it and had been tested for emissions prior to shipment; results indicated that emissions levels were below the 1977 Federal Emissions Standards of .41 grams per mile hydrocarbons (HC), 3.4 grams per mile carbon monoxide (CO), and 2.0 grams per mile oxides of nitrogen (NOx).

The Environmental Protection Agency receives information about many systems which appear to offer potential for emission reduction or fuel economy improvement 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, attempts are made to schedule tests at the EPA Emissions Laboratory at Ann Arbor, Michigan. The results of all such test projects 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 necessarily of limited applicability. A complete evaluation of the effectiveness of an emission control system in achieving performance improvements on the many different types of vehicles that are in actual use requires a much larger sample of test vehicle 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 an 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 System Description

The vehicle tested was a 3-way catalyst equipped Volvo prototype, with a 4-cylinder 130 cubic inch (2130 cc) engine and automatic transmission. The engine, which employs an overhead camshaft and cross-flow aluminum head (unlike the current U.S. version) and Bosch continuous flow fuel injection, is not currently sold in the United States.

The emission control system consists of a 3-way catalytic converter and Lambda-sond system (an oxygen sensor in the exhaust upstream of the converter). The single catalytic converter oxidizes HC and CO and reduces NOx at the same time, providing the composition of the exhaust gas remains within a narrow range. The required close control of engine air-fuel ratio is achieved by using the signal from the exhaust oxygen sensor to control the Bosch K-Jetronic continuous-type fuel injection system. No EGR or air pump is used on the system.

A detailed Test Vehicle Description table, a catalyst performance curve, and a schematic of the emission control system are included in the following pages of this report.

Test Procedure

Exhaust emission tests were conducted according to the 1975 Federal Test Procedure ('75 FTP), described in the Federal Register of November 15, 1972. Additional tests included the EPA Highway Cycle for determining highway emissions and fuel economy and a series of tests to determine particulate and sulfate emissions. These latter tests ('75 FTP's, '72 FTP's {hot start}, Highway Cycles, and 60 mph steady state tests) were performed on an electric dynamometer which can be set to the same inertia weight and horsepower loading as on the standard Clayton dynamometer. In these tests the vehicle exhaust passes through a tunnel 18 feet (5.5 m) long and 1.5 feet (.46 m) in diameter before entering the constant volume sampler (CVS). A sample is collected on a filter for each test in this series and is later analyzed for total mass of particulates and then for sulfates using an automated barium chloranilate method.

All tests were conducted using an inertia weight of 3500 pounds (1589 kg) and road load setting of 12.33 horsepower (9.20 kW) at 50 miles per hour (80.5 km/hr.). This inertia weight is 500 pounds higher than is currently used for this model vehicle, but Volvo chose the 3500 pound setting not knowing at the time of these tests the exact weight of the vehicle for which this engine - emission control package is intended.

TEST VEHICLE DESCRIPTION

Chassis model year/make - 1975 Volvo 242 DL
Emission control system - 3-way catalyst

Engine

model	B21F
type	4-stroke Otto cycle, OHC, I-4
bore x stroke	not available (NA)
displacement	130 inches^3/2130cc
compression ratio	8.5:1
maximum power @ rpm	NA
fuel metering	Bosch continuous flow fuel injection
fuel requirement	91 RON unleaded

Drive Train

transmission type	3-speed automatic
final drive ratio	4.1:1

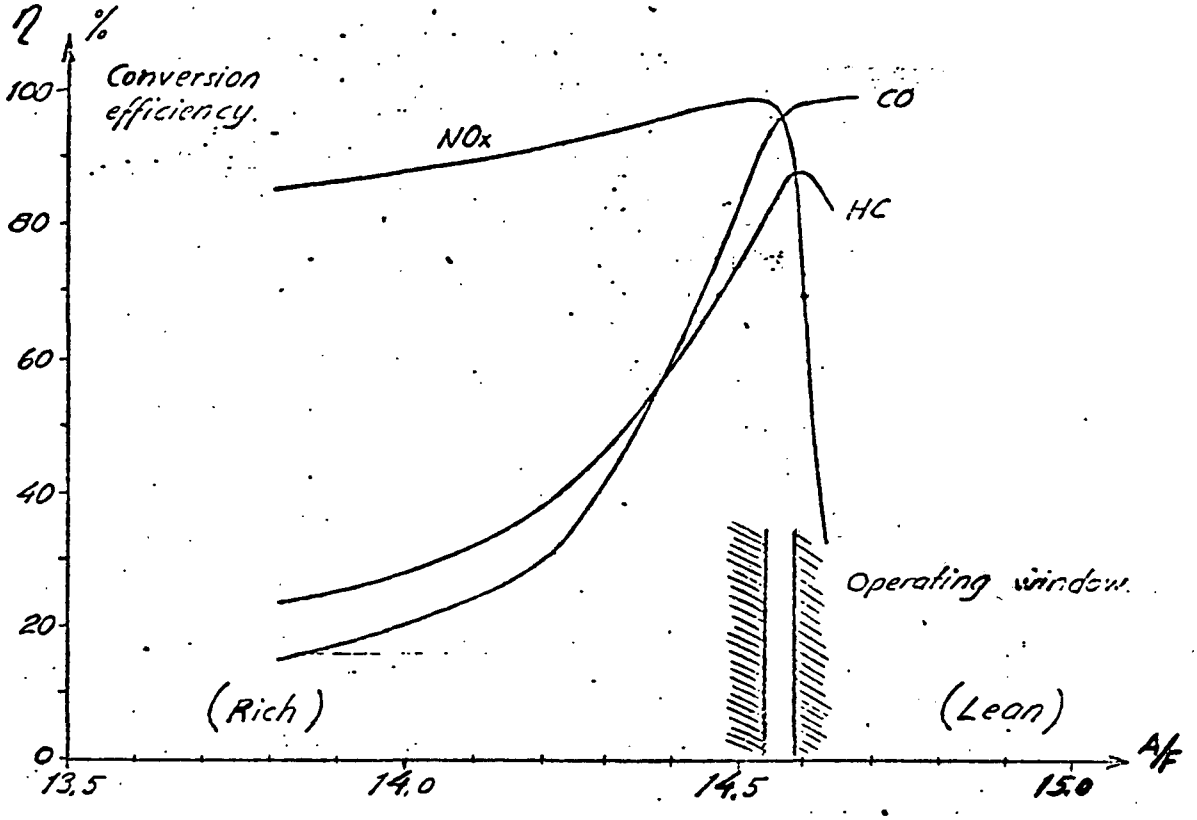
Chassis

body type	model 242, 2 door sedan
tire size	175 SR 14
curb weight	2950 lbs/1344 kg
inertia weight	3500 lbs/1589 kg
passenger capacity	5

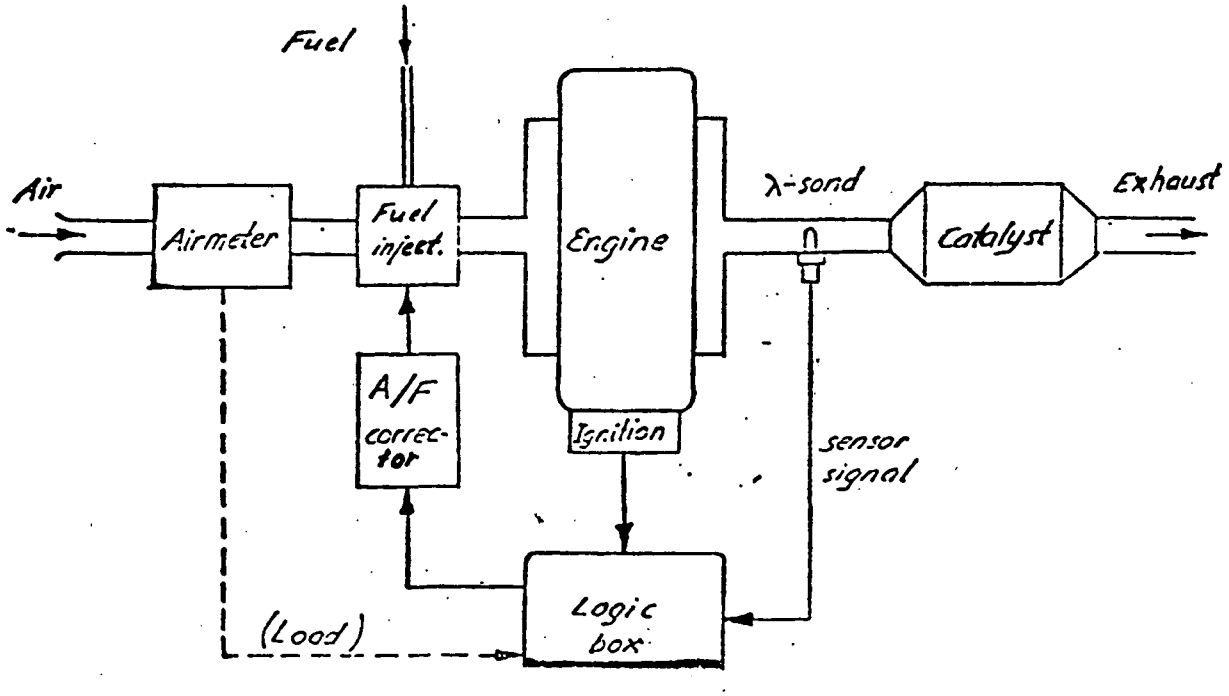
Emission Control System

basic type	Lambda-sond system and 3-way catalyst
3-way catalyst type	Engelhard TWC-1, TWC-9
substrate	NA
volume	NA
loading	NA
EGR type	None
Air injection	None
durability accumulated on system	4,000 miles each catalyst

CATALYST PERFORMANCE CURVES.



CLOSED LOOP (LAMBDA-SOND) FUEL INJECTION SYSTEM.



The vehicle was delivered with a first generation Engelhard 3-way catalyst, model TWC-1, installed. Emissions and particulates testing were performed with this catalyst. A "dummy" catalyst was then installed so that the effectiveness of TWC-1 could be determined. After this, a current model catalyst, model TWC-9, the type planned for production was installed. Four thousand miles of operation had been accumulated on this catalyst, on another vehicle, prior to shipment to the EPA laboratory. Emissions tests were performed with this catalyst at two conditions of feedback sensor control. The sensor potentiometer had been set at .401 volts and was changed to .500 volts upon request from Engelhard personnel. The purpose of this was to provide a slightly richer mixture which was felt necessary for better operation of the catalyst. No particulate or sulfate emissions tests were performed with TWC-9 installed.

Test Results

Exhaust emissions data, Highway Cycle fuel economy, and particulates and sulfates results are summarized below. The Volvo prototype vehicle met the levels required by the 1977 Federal emissions standards with both catalysts TWC-1 and TWC-9, both at 4000 miles of durability. Compared to the 1975 Volvos, the Volvo prototype, when fitted with catalyst TWC-9, delivered 5% better fuel economy. This can be seen by utilizing a formula for combining the two fuel economy values:

$$\text{Composite MPG} = \frac{1}{\frac{.55}{\text{FTP}} + \frac{.45}{\text{HC}}}$$

where FTP = fuel economy on the FTP, and

HC = fuel economy on the Highway Cycle.

This information is included in the summary along with fuel economy for two 1975 Volvo certification vehicles equipped with 4 cylinder engines and automatic transmissions, tested at 3500 pounds inertia weight.

A comparison of the emissions from the Volvo when fitted with catalyst TWC-9 (pot. setting .401 volts) with the emissions when the dummy catalyst was installed yields: 85% lower HC emissions, 92% lower CO emissions, and 57% lower NOx emissions.

Detailed emissions and fuel economy data are presented in the Appendix of this report.

Summary of '75 FTP Results and
EPA Highway Cycle Results

	Mass Emissions grams per mile (grams per kilometre)			Fuel Economy/Fuel Consumption miles per gallon (litres per 100 kilometres)		
Catalyst	HC	CO	NOx	Urban	Highway	Composite
TWC-1 Avg. of 2 tests	.22 (.14)	.90 (.56)	1.70 (1.05)	19.3 (12.2)	26.4 (8.9)	22.0 (10.7)
Dummy catalyst - 1 test	1.79 (1.11)	11.4 (7.07)	4.60 (2.85)	18.6 (12.6)	24.6 (9.6)	20.9 (11.3)
TWC-9 Pot. Setting at .40k (as before) - 1 test	.27 (.17)	.93 (.58)	1.96 (1.22)	17.9 (13.1)	23.6 (10.0)	20.1 (11.7)
TWC-9 Pot. Setting at .500 - avg. of 2 tests	.24 (.15)	1.18 (.73)	1.44 (.89)	17.8 (13.2)	24.0 (9.8)	20.2 (11.6)
1975 Volvo 245 Wagon (2 vehicles)				16.9 (13.9)	23.0 (10.2)	19.2 (12.2)
1977 Federal Emissions Standards	.41 (.25)	3.4 (2.1)	2.0 (1.2)			

Particulate and Sulfate Emissions Results

Test Type	Number of Tests	Total Particulates Milligrams per mile ±	Sulfuric Acid Milligrams per mile ±	Converted to Sulfate
'75 FTP	4	3.5 ± 0.7	0.0*	0.0
'72 FTP (Hot Start)	4	1.7 ± 0.4	0.0	0.0
Highway Cycle	8	1.1 ± 0.5	0.0	0.0
60 MPH Steady Sate	16	0.4 ± 0.2	0.0	0.0

* Below detectability. This means the sulfuric acid content was less than .1 mg per mile. Cars without catalysts often show about 3 mg per mile.

Conclusions

At low mileage, using either catalyst TWC-1 or TWC-9, the Volvo prototype vehicle met the 1977 Federal emissions standards with a small improvement in fuel economy over 1975 model Volvos. Durability testing of the system will have to be performed to determine if the system has the capability of meeting the standards at 50,000 miles, which is necessary for certification of a vehicle. Although the catalyst has shown high conversion efficiencies after 1000 hours of bench testing, further testing of the system in a vehicle is necessary to establish durability, since vehicle durability of 3-way catalyst systems historically has been a problem.

The Volvo with the TWC-1 catalyst installed emitted very low levels of both particulate and sulfate (reported as sulfuric acid mist) emissions. Both levels were the lowest obtained at this laboratory on any system tested thus far.

Table I

1975 FTP Composite Results
Mass Emissions, grams per mile
Fuel Economy, miles per gallon

Catalyst	Test No.	HC	CO	NOx	Fuel Economy
TWC-1	19-6663	.22	.74	1.73	19.3
	19-6701	.23	1.06	1.67	19.3
Dummy Catalyst	19-6735	1.79	11.4	4.60	18.6
TWC-9, .401 V setting	16-7064	.27	.93	1.96	17.9
TWC-9, .500 V setting	16-7091	.23	1.38	1.46	18.2
	15-7100	.26	.98	1.41	17.4

Manufacturer's Supplied Data

Catalyst	Odometer Mileage	HC	CO	NOx	Fuel Economy
TWC-1	0	.18	1.24	.25	17.0
TWC-1	4090	.30	1.53	1.03	17.7
TWC-1	4134	.23	1.31	1.12	17.9
TWC-1	4145	.27	1.10	.90	18.5
Dummy Catalyst	4157	1.53	12.1	5.10	18.2
	4168	1.56	10.8	4.89	18.8

Table II

1975 FTP Individual Bag Results
Mass Emissions, grams per mile
Fuel Economy, miles per gallon

	Bag 1 Cold Transient					Bag 2 Hot Stabilized					Bag Hot Transient				
Test No.	HC	CO	CO_2	NOx	Fuel Economy	HC	CO	CO_2	NOx	Fuel Economy	HC	CO	CO_2	NOx	Fuel Economy
19-6663	.61	2.95	495.0	2.30	17.7	.11	.18	466.7	1.38	19.0	.14	.13	413.2	1.98	21.4
19-6701	.57	3.89	481.0	2.43	18.1	.11	.37	461.1	1.14	19.2	.19	.23	429.6	2.13	20.3
19-6735	2.05	14.60	479.4	6.37	17.4	1.68	10.75	456.1	3.13	18.6	1.81	10.27	429.6	6.08	19.7
16-7064	.70	3.12	519.5	2.81	16.8	.13	.45	495.3	1.19	17.9	.18	.17	434.3	2.55	20.4
16-7091	.55	4.23	500.4	2.30	17.4	.14	.89	490.0	.90	18.0	.15	.15	461.5	1.88	19.2
15-7100	.69	3.39	521.4	2.08	16.8	.12	.47	519.7	.94	17.0	.20	.16	476.3	1.82	18.6

Table III

EPA Highway Cycle
Emissions Results and Fuel Economy

Mass emissions, grams per mile
Fuel Economy, miles per gallon

Catalyst	Test No.	HC	CO	NOx	Fuel Economy
TWC-1	19-6618	.07	.07	.75	25.6
	19-6701	.06	.05	.88	26.4
Dummy Catalyst	19-6735	.56	4.74	5.04	24.6
TWC-9, .401 pot setting	16-7064	.06	.03	1.83	23.6
TWC-9	16-7091	.14	.23	.27	23.5
.500 V	15-7100	.11	.16	.23	24.5

Table III

EPA Highway Cycle
Emissions Results and Fuel Economy

Mass emissions, grams per mile
Fuel Economy, miles per gallon

Catalyst	Test No.	HC	CO	NOx	Fuel Economy
TWC-1	19-6618	.07	.07	.75	25.6
	19-6701	.06	.05	.88	26.4
Dummy Catalyst	19-6735	.56	4.74	5.04	24.6
TWC-9, .401 pot setting	16-7064	.06	.03	1.83	23.6
TWC-9	16-7091	.14	.23	.27	23.5
.500 V	15-7100	.11	.16	.23	24.5

Table IV

'75 FTP Composite Results from
Electric Dynamometer During Sulfate Test Program
With Catalyst TWC-1

Mass Emissions, grams per mile
Fuel Economy, miles per gallon

Test No.	HC	CO	NOx	Fuel Economy
16-6805	.26	1.68	2.50	18.2
16-6808	.28	1.31	2.60	18.7
16-6822	.22	1.26	2.27	18.5

Table V

'72 Hot Start LA-4 Composite Results
from Electric Dynamometer During Sulfate
Test Program with Catalyst TWC-1

Mass Emissions, grams per mile
Fuel Economy, miles per gallon

Test No.	HC	CO	NOx	Fuel Economy
16-6793	.14	.30	2.24	19.3
16-6806	.14	.35	2.44	18.8
16-6809	.16	.32	2.49	19.3
16-6823	.14	.51	2.42	19.0

Table VI

Highway Cycle Results from Electric
Dynamometer During Sulfate Test Program
with Catalyst TWC-1

Mass Emissions, grams per mile
Fuel Economy, miles per gallon

Test No.	HC	CO	NOx	Fuel Economy
16-6792	.08	.04	2.53	24.4
16-6793	.12	.16	2.69	24.5
16-6805	.14	.24	3.08	23.4
16-6806	.09	.04	2.89	23.5
16-6808	.13	.14	3.17	23.3
16-6809	.09	.05	3.21	22.5
16-6822	.13	.18	2.98	24.0

Table VII

60 mph Steady State Results from
Electric Dynamometer During Sulfate Test
Program with Catalyst TWC-1

Mass Emissions, grams per mile
Fuel Economy, miles per gallon

Test No.	HC	CO	NOx	Fuel Economy
16-6807	.06	.02	2.47	25.2
16-6807	.07	.02	2.75	23.3
16-6810	.07	.02	2.93	23.8
16-6810	.07	.02	3.11	22.8
16-6824	.07	.01	3.27	23.4
16-6824	.07	.01	3.01	23.6