Evaluation of a Turbocharged TCCS Powered Plymouth Cricket

October 1974

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

Background

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 systems 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 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 the EPA evaluation tests can be considered to be quantitatively valid only for the specific test car used, however, it is reasonable to extropolate 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.

As part of the EPA stratified charge evaluation program, the Emission Control Technology Division of the Office of Mobile Source Air Pollution Control contacted Texaco, Incorporated concerning the loan of a test vehicle powered by a Texaco Controlled Combustion System (TCCS) engine. A vehicle was supplied courtesy of Texaco and a test program was conducted by the Technology Assessment and Evaluation Branch.

Vehicle Description

The vehicle tested was a catalyst-equipped 1972 Plymouth Cricket, with a turbocharged 4-cylinder 141 cubic inch, TCCS engine and 3-speed automatic transmission. The car is described in detail in the Vehicle Description table on the following page and the TCCS concept is described in the text following this table.

TEST VEHICLE DESCRIPTION

Chassis model year/make - Cricket '72/Plymouth
Emission control system - Stratified charge engine with catalyst

Engine

type	turbocharged/4 cycle/4 cylinder/ liquid cooled/ stratified charge
bore x stroke	3.875" x 3.000" (98.2mm x 76.2mm)
displacement	141 in^3 (2300cc)
compression ratio	10:1
maximum power @ rpm	80 hp (107 Kw) @ 4000 rpm
fuel metering	Roosa Master Diesel injection (pump and injectors)
fuel requirements	multi-fuel (limited by injection pump capabilities)

Drive Train

transmisstion	unitized construction front engine, rear wheel drive
final drive ratio	3.23

Chassis

tire size	155 SR 13 radial
curb weight	2200 lbs. (1000 Kg)
inertia weight	2500 lbs. (1140 Kg)
passenger capacity	4

Emission Control System

basic type	Catalyst
oxidation catalyst location	immediately down stream of turbo & @ normal rear silencer
substrate	gam ma alumina on inconel mesh
volume	1.6 litres after turbo 2.0 litres @ rear silencer
loading	0.07 oz. platinum after turbo 0.12 oz. platinum at rear silencer

The TCCS engine concept has multifuel capabilities. A Diesel type direct cylinder injection system and a long duration constant potential ignition system is incorporated in the TCCS engine. Figure 1 illustrates the basic arrangement of components. The process works in the following manner. During the intake stroke a swirl is inparted to the fresh air charge. This is accomplished by tangential intake port to cylinder geometry and a masked or shrouded intake valve (see Figure 1). During compression the swirl rate is increased due to conservation of momentum as the already swirling air is forced into the smaller (than cylinder bore) piston cup. Injection and ignition commence approximately 15 to 25 degrees before top dead center. Fuel is injected into the swirling air and at the same time the ignition begins sparking. The ignition plug continues sparking while the injected fuel is mixed with air and carried to the plug by the swirl. At the plug ignition of the mixture is initiated and during the process burning mixture is swirled away as fresh mixture is continually brought to the ignition source. While injection is occurring the combustion is proceeding in a manner similar to that of a continuous, external combustion burner. When the injection is complete the spark is shut off and the remainder of the expansion and exhaust process occurs as in a conventional gasoline engine.

Since the fuel is burned almost at the same time it enters the combustion chamber the fuel/air residence time is very short and no "end gas" mixture is formed thus the engine has no octane requirement. Since ignition is via spark the engine has no cetane requirement. This insensitivity to octane and cetane is typical of external, continuous combustion systems such as used in turbines or steam engines but unique as far as internal combustion engines are concerned.

Unlike conventional gasoline engines, the TCCS engine does not require intake air throttling to maintain good combustion. The air/fuel mixture is always in the ignitable range at the spark plug location despite the overall lean mixture of 100:1 that can be realized during part load operation. The ability to run extremely lean "overall" is a feature of most stratified charge concepts and the Diesel engine. Unlike the conventional gasoline engine stratified charge and Diesel engines depend on "local" rather than "overall" mixture ratios for good combustion. The advantage of the ability to run without throttling is that the losses associated with drawing the fresh air charge into the cylinder (pumping losses) are lessened. This can result in improved economy over the conventional gasoline engine at partial loads. A historical problem with unthrottled operation of open chamber stratified charge engines like the TCCS, however, has been high hydrocarbon emissions. Throttling can be applied to the engine to raise exhaust temperatures and reduce HC emissions but when this is done, economy suffers.

Exhaust gas recirculation (EGR) had previously been demonstrated as a highly effective NOx reduction technique which can be applied to stratified charge engines like the TCCS. The test vehicle, however, was not equipped with EGR as this particular vehicle was set up for optimum fuel economy with lesser attention to low NOx emissions.

Test Procedure

Exhaust emissions tests were conducted according to the 1975 Federal Test Procedure ('75 FTP) described in the Federal Register on November 15, 1972. In addition several EPA Highway Cycles were ran on this vehicle. All testing was conducted at 2500 lbs. inertia.

During testing three fuels were used. These included indolene unleaded gasoline, number 2 Diesel fuel, and a wide boiling range distillate fuel supplied by Texaco. The wide boiling range fuel supplied by Texaco was blended from available fuel stocks and represents a theoretical high refinery yield fuel which has no octane or cetane specification. Table 1 contains Texaco's test information on this fuel.

For both the Diesel fuel and the wide boiling range fuel vehicle testing a continuous analysis, heated flame ionization detector (FID) technique similar to that used for light duty Diesel testing was used to eliminate condensation losses which can occur when bag samples and "cold" FIDs are used to measure exhaust from vehicles fueled by fuels containing higher molecular weight hydrocarbons.

Test Results

'75 FTP gaseous emission test results are given in the attached tables 2, 2a, 3, 3a, 4 and 4a for the three fuels. For the Diesel fuel and wide boiling range fuel testing, hydrocarbon emission results have been omitted for the cases where heated flame ionization measurement was not used. As noted in these tables the vehicle was tested in two different configurations. After the initial testing Texaco requested that the vehicle be returned to them for an in-house demonstration project. Scuffed cylinders were discovered during a check-up on arrival at Texaco. The scuffing may be partly a result of low engine oil pressure as observed when the vehicle was delivered to EPA. Texaco rebuilt the engine and added an intake air throttle to achieve better hydrocarbon control during the remaining EPA tests. The throttle was set up such that throttling is only achieved at idle and deceleration.

SCHEMATIC, TCCS

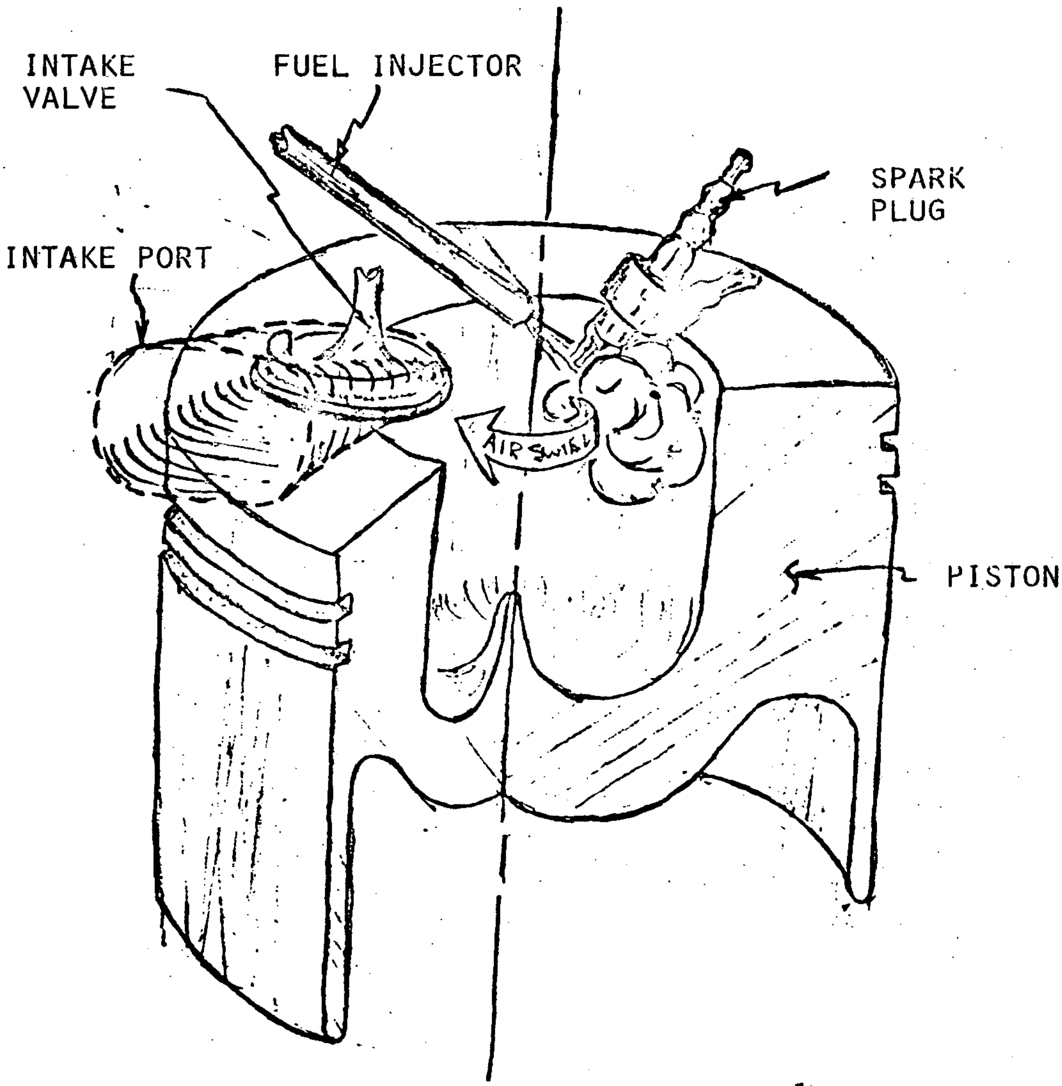

FIGURE 1

The data in the attached tables of results illustrate that while emission levels better than 1975 interim standards can be achieved, high hydrocarbon emissions prevented achievement of the 1977 levels of .41 gpm HC, 3.4 gpm CO and 2.0 gpm NOx. It appears that the engine rebuild and throttling had little influence on emissions but it did cause a 10 to 15% loss in fuel economy as illustrated in table 4. This would be expected due to the increase pumping loss which occurs during throttled conditions.

Fuel economy comparison of the initial gasoline testing of this TCCS vehicle with the '75 FTP sales-weighed results from the 1975 certification car fleet shows 35% better fuel economy (see table 4 for the TCCS Cricket). The TCCS vehicle run on Diesel fuel gets about equivalent economy to a Peugeot 204 Diesel passenger car of the same test inertia (see table 2).

Highway cycle results are given in table 5 and 5a. All highway cycle testing was conducted after the engine rebuild. No gasoline fuel data is available for the TCCS vehicle tested over the highway cycle. Comparison with a Peugeot 204 Diesel of similar weight shows that this TCCS vehicle gets slightly better fuel economy.

Aldehyde levels as measured by the EPA MBTH method are given in table 6. In comparison with other late model cars this TCCS vehicle appears to yield low aldehyde emissions. When compared with a Peugeot 504 Diesel aldehydes appear equivalent.

Conclusion

A turbocharged catalyst equipped TCCS powered Plymouth Cricket demonstrated the ability to meet 1975 interim levels on three different fuels with high fuel economy. Durability of the catalyst, however, was not determined.

Compliance with the 1977 and later HC standard of .41 gpm will require additional control devices or basic combustion improvement beyond that demonstrated in this test.

Table 1

Wide Boiling Range Fuel

Stock	Vol %
Hvy. St. Run	13
Lt. St. Run	12
FCC	25
Diesel Fuel	25
Avjet	25

Identification	214-38
Gravity, API	46.1
Sulfur, % (LAMP)	0.16
TEB, ml/gal	< 0.05
RVP, lbs	3.3
Distillation, ASTM, °F	
IBP	121
20%	225
50%	379
90%	532
Octane number	
ASTM-R (RON)	60
ASTM-M (MON)	48
Cetane Number	34.8
% Hydrogen	13.7
% Carbon	86.3
Gross Heating Value	19535 BTU/lb.

Table 2

Diesel Fuel Results

'75 FTP Results

Test No.	HC g/mi	CO g/mi	NOx g/mi	Fuel Economy MPG
15-55*	0.89	0.95	1.79	30.4
15-41*	N/A	2.30	1.94	31.2
15-43*	N/A	2.40	1.99	30.7
Avg. wo/throttling	.89	1.88	1.91	30.8
16-4994	1.01	0.78	1.76	28.9
16-5046	0.98	1.16	1.88	27.9
Avg. w/throttling	1.00	.97	1.82	28.4

* Early testing before engine rebuild and without idle/deceleration throttle

Peugeot 204 Diesel '75 FTP @ 2500 lbs; 28.3 mpg

Table 2a

Diesel Fuel Results

'75 FTP Results

Test No.	HC g/km	CO g/km	NOx g/km	Fuel Consumption 1/100 km
15-55*	0.55	0.59	1.11	7.7
15-41*	N/A	1.43	1.21	7.5
15.43*	N/A	1.49	1.24	7.7
Avg. wo/throttling				7.7
16-4994	0.63	0.48	1.09	8.1
16-5046	0.61	0.72	1.17	8.4
Avg. w/throttling				8.3

* Early testing before engine rebuild and without idle/deceleration throttle

Peugeot 204 Diesel '75 FTP @ 2500 lbs; 8.31 1/100 km

Table 3

Wide Boiling Range

Fuel Results

Test No.	HC g/mi	CO g/mi	NOx g/mi	Fuel Economy MPG
15-24*	N/A	1.10	1.47	28.8
15-27*	N/A	0.75	1.59	30.4
15-34*	0.88	1.05	1.78	29.8
Avg. wo/throttling	0.88	0.97	1.61	29.7
15-5063	0.70	0.82	1.78	25.3
15-5064	0.61	0.74	1.94	24.8
Avg. w/throttling	.66	.78	1.86	25.1

* Early testing before engine rebuild and without idle/deceleration throttle

Table 3a

Wide Boiling Range

Fuel Results

Testing No.	HC g/km	CO g/km	NOx g/km	Fuel Consumption 1/100 km
15-24*	N/A	0.68	0.91	8.2
15-27*	N/A	0.47	0.99	7.7
15-34*	0.55	0.65	1.11	7.9
Avg. wo/throttling	.55	.60	1.00	7.9
15-5063	0.44	0.51	1.11	9.3
15-5064	0.38	0.45	1.21	9.5
Avg. w/throttling	.41	.49	1.16	9.4

* Early testing before engine rebuild and without idle/deceleration throttle

Table 4

Gasoline Results

'75 FTP Results

Testing No.	HC g/mi	CO g/mi	NOx g/mi	Fuel Economy MPG
15-46*	1.48	0.50	1.87	27.4
15-49*	1.42	0.50	1.79	29.6
15-50*	1.21	0.50	1.87	28.3
Avg.	1.37	0.50	1.84	28.4

* Early testing before engine rebuild and without idle/deceleration throttle

Sales weighted fuel economy from '75 Cert. results for 2500 lb. class is 21.2 mpg

Table 4a

Gasoline Results

'75 FTP Results

Testing No.	HC g/km	CO g/km	NOx g/km	Fuel Consumption 1/100 km
15-46*	0.92	0.31	1.16	8.6
15-49*	0.88	0.31	1.11	8.0
15-50*	0.75	0.31	1.16	8.3
Avg.	0.85	0.31	1.14	8.8

* Early testing before engine, rebuild and without idle/ deceleration throttle

Sales weighted fuel consumption from '75 Cert. results for 2500 lb. class is 11.1 1/100 km

Table 5

Highway Cycle Results

Test No.	Fuel	HC g/mi	CO g/mi	NOx g/mi	Fuel Economy MPG
16-4994	Diesel	0.43	0.37	1.57	40.6
15-5063	Wide Boiling Rg	0.33	0.37	1.47	35.9
15-5064	Wide Boiling Rg	N/A	0.31	1.62	36.0
Avg.	Wide Boiling Rg	0.33	0.34	1.56	36.0
	Gasoline	N/A			

2500 lb wt class Sales Weighted Highway Economy from '75 Cert = 31.2 mpg

Peugeot 204 Diesel Highway Economy Tested at 2500 lbs = 38.6 mpg

Table 5a

Highway Cycle Results

Test No.	Fuel	HC g/km	CO g/km	NOx g/km	Fuel Consumption 1/100 km
16-4994	Diesel	0.27	0.23	0.98	5.79
15-5063	Wide Boiling Rg	0.21	0.23	0.91	6.55
15-5064	Wide Boiling Rg	N/A	0.19	1.02	6.53
Avg.	Wide Boiling	0.21	0.21	0.97	6.54
	Gasoline	N/A			

2500 lb wt class Sales Weighted Highway Consumption from '75 Cert = 7.5 1/100 Km

Peugeot 204 Diesel Highway Economy tested at 2500 lbs = 6.1 1/100 Km

Table 6

MBTH Aldehyde Results

Test No.	Fuel	Composite '75 FTP HC gm/mi	ALD'Y g/mi	% ALD'Y
15-50	Gasoline	1.21	0.030	2.5
15-55	Diesel	0.89	0.057	6.4
15-5063	Wide Boiling Rg.	0.70	0.057	8.1
15-5064	Wide Boiling Rg.	0.61	0.048	7.9
'73 Duster (225 CID Eng.) Avg. 3 tests		1.80	0.116	6.5
'73 Maverick (302 CID Eng.) Avg. 3 tests		2.25	0.104	4.6
Peugeot 504 Avg. 2 tests	Diesel	0.84	0.048	5.7

APPENDIX

Individual 1975 FTP Bag Results

Test No.	Fuel	BAG 1 HC g/m	BAG 1 CO g/m	BAG 1 CO_2 g/m	BAG 1 NOx g/m	BAG 1 Eco. mpg	BAG 2 HC g/m	BAG 2 CO g/m	BAG 2 CO_2 g/m	BAG 2 NOx g/m	BAG 2 Eco. mpg	BAG 3 HC g/m	BAG 3 CO g/m	BAG 3 CO_2 g/m	BAG 3 NOx g/m	BAG 3 Eco. mpg
15-55*	Diesel	1.40	1.68	355.9	1.95	28.3	0.70	0.44	331.6	1.65	30.7	0.86	1.37	313.2	1.94	32.1
15-41*	"	N/A	4.19	354.8	2.17	27.9	N/A	1.73	316.0	1.82	31.8	N/A	1.88	303.1	1.99	32.2
15-43*	"	N/A	3.41	353.2	2.29	28.2	N/A	2.21	320.8	1.79	31.3	N/A	1.86	318.2	2.16	31.6
16-4994	"	1.55	1.99	363.0	1.97	27.6	0.87	0.28	359.5	1.62	28.2	0.95	0.80	319.5	1.86	31.6
16-5046	"	1.54	3.01	379.1	2.21	26.3	0.89	0.47	365.1	1.68	27.7	0.77	1.09	340.3	1.99	29.7
15-24*	W.B.R.F.**	N/A	2.61	340.4	1.50	26.2	N/A	0.59	332.1	1.37	28.3	N/A	0.99	300.7	1.63	31.2
15-27*	"	N/A	0.92	317.8	1.75	29.6	N/A	0.65	306.7	1.44	30.6	N/A	0.83	305.7	1.44	30.7
15-34*	"	1.43	2.23	343.9	1.97	27.0	0.99	0.60	310.8	1.61	30.6	0.75	1.02	298.8	1.96	31.4
15-5063	"	1.23	2.00	378.0	1.97	24.6	0.58	0.36	385.7	1.67	24.5	0.51	0.81	341.4	1.85	27.6
15-5064	"	1.15	1.64	385.8	2.06	24.2	0.41	0.36	389.1	1.79	24.2	0.39	0.76	357.8	2.15	26.4
15-46*	Gasoline	1.85	0.99	354.1	2.14	24.5	1.37	0.26	312.5	1.67	28.0	1.42	0162	303.3	2.05	28.7
15-49*	"	1.97	0.94	327.1	1.97	26.5	1.40	0.32	288.1	1.61	30.3	1.01	0.54	281.2	2.02	31.1
15-50*	"	1.25	0.88	350.5	2.33	24.9	1.41	0.29	299.9	1.58	29.1	0.81	0.53	293.5	2.07	29.9

* Early testing before engine rebuild and without idle/deceleration throttle

** Wide boiling range fuel