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Exhaust Emissions From A Turbocharged Texaco Combustion Process (TCP) Stratified Charge Engine

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John C. Thomson
Division of Motor Vehicle Pollution Control
National Air Pollution Control Administration
Department of Health, Education, and Welfare

Subject: TCP Jeep test program results

Texaco, Inc., through a U. S. Army contract has built an updated version of their stratified charge engine. Because preliminary Texaco data showed a significant reduction in emissions from previous NAPCA results,[1] an emission test program was conducted on the new engine.

The engine was installed in the same M-151-1/4 ton army jeep used in the previous test. Tests were conducted on the chassis dynamometer using both continuous analysis and the constant volume sampling system. Two fuels, and a mixture of the fuels, were used and both hot and cold starts were monitored.

A standard L-141 engine (four cylinder 3-7/8" bore, 3" stroke - 141.5 CID) was modified by Texaco to incorporate the required features for operation on their stratified charge, multifuel, turbocharged, combustion process. This system utilizes high pressure cylinder injection of the fuel into a controlled inlet air swirl pattern in conjunction with spark ignition. No throttling of the inlet air is required and load control is accomplished by control of the injected fuel quantity only. Turbocharging and a special ignition system were added in their latest design to improve combustion and reduce smoke; fuel to 115/145 aviation gasoline may be used. For these series of tests CITE fuel (MIL-F-45121B) and Indolene 30 (see Appendix) were used along with a mixture of 50% gasoline and 50% CITE.

The following tests were conducted:

a) 1968 Federal Procedure (modified) for exhaust emissions using Indolene 30 and a separate test using 50% CITE, 50% gasoline.

b) 9 cycles of the 7-mode Federal cycle used with constant volume sampling (CVS) on both Indolene 30 and the CITE-gasoline mixture.

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[1] See Exhaust Emissions From Texaco Combustion Process (TCP) Stratified Charge Engine. National Air Pollution Control Administration, Ypsilanti, Michigan August 1968.

c) Selected hot cycles using both Indolene 30 and straight CITE.

The Federal Procedure data were obtained with NDIR instruments while both NDIR and FID were used in the CVS technique. The Saltzman method and the Whittaker "NO_x Box" were used for determination of oxides of nitrogen in the CVS sample.

Dynamometer Results

Mass emission results for the Turbocharged TCP jeep along with previous data on a standard jeep are shown in Figure 1. Both tests are 9 cycle repeats of the Federal cycle.

The results of the dynamometer evaluation based on mass emissions clearly show that the turbocharged TCP jeep engine greatly reduces all of the measured exhaust components.

The effects of dilution with an unthrottled air engine, as in the TCP jeep, leads to extremely high air-fuel ratios. Due to the low concentrations of CO and CO_2 caused by non-homogeneous combustion of a stochiometric mixture surrounded by large quantities of air, the use of the conventional correction factor used in the Federal test procedure appears to bias exhaust gas hydrocarbon results.[2] Because of this, the correction factor was not applied to the data and the concentration values shown in Figure 2 were calculated using revised weighting factors. The new weighting factors were calculated by the procedure originally used by the State of California but based on air flow data from the previous TCP engine. The additional quantity of air flow caused by the turbocharger is not significant in the portions of the cycle measured.

The original mode breakdown and percent of total volume in each mode is the product of the percent time in mode and the average engine air flow in each mode. The final weighting factors were obtained by combining the percent

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2 See M. W. Jackson, ET. AC, The Influence of Air-Fuel Ratio, Spark Timing, and Combustion Chamber Deposits on Exhaust Hydrocarbon Emission. SAE 486A, March 1962, Appendix D.

of total volumes in each mode in the manner used by the State of California in the design of the original seven-mode cycle. (For further details see "The California Motor Vehicle Emissions Standards" by G. C. Hass, SAE paper number 210A August 1960). The weighting factors used for the TCP engine are:

Idle	.094
0-25mph	.139
30	.099
30-15	.197
15	.081
15-30	.292
50-20	.098

Figure 2 compares results taken in previous tests with the naturally aspirated TCP jeep and those taken with the Turbo-charged jeep. This shows an approximate 50% reduction in Hydrocarbons with a 2.5% reduction in carbon monoxide.

Figure 3 reports the results of hot start cycles run to provide confirmation of repeatability.

In all tests but one a manual dump valve was used to prevent pump leakage during the 50-30 mile per hour decel. A revised pump with improved features is now under investigation by Texaco, Inc. The solution of the pump leakage problem would prevent potential engine run away at light load and ensure full cut off on deceleration. The only major engine problem during the program was a broken oil pump and the repair should not influence the emission test results.

Smoke

Due to the Diesel type combustion there is some production of soot and smoke. To protect the instrumentation, a pre-filter was placed in the continuous sample line. At the conclusion of testing, no evidence of hangup in the sample lines or the CVS unit was found. Attempts to measure smoke and odor on this vehicle will be made in the near future.

Summary of Results

a) The addition of the turbocharger and an improved ignition system have shown significant improvements over the standard vehicle and the previous TCP engine.

b) Mass emissions show large improvements over the standard vehicle with a 10 fold reduction in CO, a 4 fold reduction in NO_x and a reduction of 1/2 in HC.

c) A small fuel effect on emissions was detected although this may be due to instrument response.

FIGURE 1

Mass Emission Results (CVS)

Indolene 30 fuel

	Turbocharged TCP	Standard M-151
HC gm/mile	3.07	8.0
CO gm/mile	10.30	100.9
CO_2 gm/mile	361.68	---
NO_x gm/mile	1.07	4.0

50% CITE / 50% Gasoline

	Turbocharged TCP
HC gm/mile	2.90
CO gm/mile	11.39
CO_2 gm/mile	332
NO_x gm/mile	1.51

FIGURE 2

Concentrations - Dynamometer
1968 Federal Procedure

		Naturally Aspirated TCP Indolene	Turbocharged TCP Indolene	Turbocharged TCP Gas/CITE 50/50
Cycles	1-4			
	Hydrocarbon	222ppm	115ppm	120ppm
	Carbon Monoxide	.18%	.15%	.20%
Cycles	6-7			
	Hydrocarbon	175ppm	97.9ppm	94ppm
	Carbon Monoxide	.17%	.12%	.13%
Weighted Average				
	Hydrocarbon	192ppm	104ppm	103ppm
	Carbon Monoxide	.17%	.13%	.15%

FIGURE 3

Constant Volume Sampling Results

Type of Test	Fuel Used	HC FID gpm	CO NDIR gpm	CO_2 NDIR gpm	NOx gpm	Subtractive Hydrocarbon % of total P+B	0	A*	1968 Federal Procedure Results HC NDIR ppm (as C_6)	CO NDIR %
Hot Start Fed Cert No decel dump	Indolene	----	-----	----	----	---	--	--	106	.17
Hot Start Fed Cert Manual decel dump	Indolene	----	-----	----	----	---	--	--	111	.18
Cold Start Fed Cert and CVS	Indolene	3.07	10.3	362	1.07	40	29	30	104	.13
Hot Start CVS	Indolene	2.34	9.4	----	.98	33	29	38	---	---
Cold Start Fed Cert and CVS	50% CITE 50% Gas	2.90	11.39	332	1.51	38	27	35	103	.15
Hot Start Fed Cert and CVS	Indolene	2.91	9.19	336	1.86	40	23	37	119	.15
Hot Start Fed Cert and CVS	CITE	2.33	10.33	321	1.80	41	35	24	81	.22

*P+B = Parafine plus Benzene
O = Olefins
A = Aromatics

APPENDIX
Fuel Inspection Data

	CITE Fuel Referee Grade MIL-F-45121B	Indolene
Gravity,° API at 60 F	48.3	-----
Gravity, Specific at 60 F	0.7870	----
Viscosity, cs at - 30 F	4.12	----
100 F	1.00	----
Distillation, ASTM, F		
IBP	152	75-95
10%	244	120-135
50%	362	200-230
90%	458	300-325
EP	478	415
RVP	1.7	8.7-9.2
FIA - Aromatics, %	19.2	35
Olefins, %	2.1	10
Saturates, %	78.7	55
Octane Number (RON)	------	100
TEL Content, ml/gal	------	3.1-3.3
Cetane No.	38.0	----