Technical Report

A Study of One Gasoline-Fueled Engine Line Comparing Emission Results Between 1969 Engines and 1979 Engines on Three Test Procedures: the Heavy-Duty Transient Engine Test, the Heavy-Duty 9-Mode Engine Test, and the Light-Duty Truck Chassis Test

by

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I. Summary

The 1977 Amendments to the Clean Air Act mandated EPA to set new emission standards for heavy-duty (HD) vehicles or engines for model years 1983 and 1985. These new standards were to represent a percentage reduction "from the average of the actually measured emission from heavy-duty gasoline-fueled vehicles or engines . . . manufactured during the baseline model year." The baseline model year was defined as the last model year in which engines were uncontrolled with respect to a given pollutant. For the 1983 HC and CO standards, the baseline model year (MY) is 1969. For the 1985 NOx standards, 1972 and 1973 have been determined to be the baseline model years. (1972 was chosen to reflect the fact that some 1973 models were already equipped with NOx controls).

EPA has initiated a testing program to determine these baseline emission levels. This testing program includes multiple transient tests on each baseline engine, during which emissions are measured by the critical flow venturi constant volume sample CFV-CVS technique. Additional testing on each engine includes the current 9-mode certification procedure modified to use the CVS bag procedure.

As part of the testing program, current technology heavy-duty (HD) and light-duty truck (LDT) engines have also been tested. In some cases these late model engines are direct descendents of the 1969 versions. Results from the first such family line tested showed a striking contrast in emission results between the transient test and the current 9-mode test. This contrast was most evident with carbon monoxide (CO) emissions. The later model year engines from this particular engine line exhibit significantly higher CO emissions not only over the transient test, but also when compared to other current technology engines tested under the same transient conditions. The contrast for HC emissions was not as great. The HC emissions from the later versions of this engine line were comparable to other current technology engines.

Interest in the CO contrast led to limited experimentation with additional emission control hardware retrofitted to these later model year engines. Data from these tests show that CO from the modified engines was reduced by over 99 percent on the 9-mode test relative to the average of essentially the same 1969 engines. Yet, the emission levels mesured on the transient test from the modified late model engines indicated only a 30-40 percent reduction (relative to their 1969 counterparts). The average of the 1969, 350 engines is similar to the estimated 1969 sales weighted baseline. Therefore, the CO reduction from the sales weighted baseline for the modified late model engines is in the same range (35-43%). The 1977 Clean Air Act Amendments require a 90 percent reduction of CO.

The high level of CO emissions from these engines on the transient test leads to the conclusion that these particular 1979 engines actually pollute at levels approaching uncontrolled levels in the real world. Analysis of the brake specific fuel consumption (BSFC) supports this conclusion (Table 6), if one assumes that similar fuel rates with similar CO levels indicates a similar degree of applied control technology.

The cause for the high CO emissions on the transient test appears to be traceable to the particular type of carburetor (air valve) used on the later model year engines. Since the carburetor calibration and design are part of the emission control system, the test data generated indicates that the relationship between emission reductions on the 9-mode and emission reductions in the real world can be highly dependent on the emission control system used. Certainly, for the engines tested, a reduction of CO emissions on the 9-mode test resulted in little reduction on the transient test procedure.

The inclusion of an engine from a 1979 LDT in the testing program generated some interesting data. Based on the very high emission levels from this engine, one concludes that emission levels are quite sensitive to load (avg. power). The current LDT compliance procedure tests LDTs at a weight approximately equal to empty weight. The emission sensitivity of this particular LDT, and, LDTs in general, to load is of concern only if the LDT compliance procedure does not load the vehicles in a representative manner.

II. Test Procedure

The program test schedule consisted of approximately three cold start transient tests per engine (reference Federal Register, Vol. 44, No. 31, February 13, 1979; Proposed Gaseous Emission Regulations - 1983 and Later Model Year Heavy-Duty Engines, Subpart N). In one case (1979, 350-CID) only two tests were run on the engine due to time constraints.

Bag samples from a CFV type CVS of approximately 1500 SCFM were used to collect emissions. One deviation from the Proposed Rules involved collecting a separate bag sample for each of the four segments that make up the test cycle. The Proposed Rules use only one bag sample for the entire cycle. The change was made for the purpose of collecting additional data on the baseline engines.

In addition to the transient tests, one to three hot-start 9-mode tests (reference 40 CFR 86, Subpart D) were run on each engine. The 9-mode test cycle was modified so that the CVS technique could be used to sample emissions. The modifications included lengthening the cycle modes from one minute to five minutes to obtain a sufficient bag sample. Also, only one cycle (9-modes) was run instead of the usual two cycles (18 modes). This was done to keep the length of the test as short as possible. Data from the CVS 9-mode agrees well with data obtained by the Subpart D test procedure (see Table 2).

In one case, a late model current technology engine was obtained with the engine in a light-duty truck (LDT) chassis. Three LDT Federal Emissions Chassis tests were performed on this engine/vehicle prior to removing the engine.

III. Test Engines

Some of the late model engines tested were, for all practical purposes, direct descendents (i.e., essentially the same engine) of 1969 engines. One 1979 heavy-duty engine and one 1979 light-duty truck engine, with the exception of emission control devices, closely resembled two 1969 350-CID engines (Table 1). The LDT engine was obtained in a van-style chassis.

The certified configuration of the 1979 350-CID heavy-duty engine included parameter calibrations (i.e., engine mod), and AIR, but no EGR. The certified configuration of the 1979 400-CID light-duty truck engine included parameter calibrations, EGR, EFE, and a 260 cubic inch pellet-type oxidation catalyst (OC).

The 1979 400-CID light-duty truck engine was tested before the 1979 350-CID heavy-duty engine, but after the two 1969 engines had been tested. The light-duty truck was the first catalyst engine tested at EPA on the transient cycle. The extremely high CO data on the 400-CID engine compared to the 1969 engines led to some limited emission control system modifications on both the 1979 400-CID light-duty truck engine and the 1979 350-CID heavy-duty engine. The only modifications to the 400-CID engine was the addition of an AIR system (Table 1). The 350-CID heavy-duty engine modifications consisted of the addition of the 260 cubic-inch catalyst from the 400-CID engine (Table 1), and the use of unleaded fuel. No other adjustments of engine parameters or calibrations were attempted. Table 1 lists the engines and the various configurations tested.

IV. Results

A comparison of mean test results between the 1969 350-CID engines tested and the 1979 engines in the certified configuration is shown in Table 2. The transient CO results from the later model year engines are quite high. Possibly of equal concern, however, is the relationship of the transient CO results to the 9-mode results between the four engines. The contrast between the test procedures is even more graphically demonstrated in Table 3, which shows the effect of the emission control system modifications on the 1979 engines. The modified control systems virtually eliminated both CO and HC emissions on the 9-modal test. Yet, on the transient test, the modified systems showed only a marginal improvement in CO emissions. The modified control system did, however, show a fairly significant reduction in transient HC emissions.

Table 4 provides a perspective of the emission levels of the 1979 engines as a percentage of emission reduction from the average of the parent 1969 engines. Both the light-duty truck and the heavy-duty late model engines in their modified configurations showed over a 99% reduction in CO on the 9-mode test. But, on the transient test, only a 35-43 percent reduction (Table 5) in CO emissions is realized when compared to the estimated 1983 standards (based on engines tested as of March 15, 1979). The HC levels on the transient test did, however, show a significant reduction (Table 5) from the estimated baseline. The certified configurations showed a 75-82 percent reduction while the modified versions ranged from 82-92 percent reduction.

Table 6 lists the average brake specific fuel consumption (BSFC) over the individual test segments as determined by the carbon balance method. The BSFC values between the certified configuration and the modified configurations of both the 350- and 400-CID engines vary more than would be desirable. However, it should be recognized that these measurements are taken over a very short time span (approximately 300 seconds). Because of the short measurement time, slight differences in the measured values tend to be magnified.

The general trends of the data, however, are interesting. For instance, the heavy-duty 1979 350-CID 4-barrel engine tends to show better or equivalent fuel economy on the cold-start NYNF (non-freeway) segment than the 1969 350 2-barrel engine, but poorer fuel economy on the hot-start NYNF segment and both LAF (freeway) segments. The 1979 LDT (400-CID 4-barrel) engine, on the other hand, tends to show better fuel economy than the 1969 engines for all segments except the LAF segment where the 1969 and 1979 engines are nearly comparable. The exact meaning of these trends is still uncertain. Hopefully, additional data from other engines tested in the program will more clearly indicate fuel economy effects of the marginal CO control of the late model engines. The data does, however, tend to inicate that previous claims about substantial fuel economy penalties associated with more stringent 9-mode standards (i.e., 1979 HD Interim) may be misleading in terms of real-world fuel economy.

Earlier it was mentioned that the 400-CID light-duty truck engine was obtained in a light-duty chassis. Both EPA and the manufacturer ran several light-duty truck chassis tests on this vehicle (21.0 roadload HP). The results in grams per mile are found in Table 7. Of interest are the grams per mile derived from the heavy-duty transient test, also shown in Table 7. Distance traveled (miles) on the heavy-duty test are derived by multiplying the average speed 1/ for each segment by the time spent within the segment. Grams per mile are then determined by substituting miles traveled for BHP-HR in the standard cold/hot emission calculation. 2/

V. Conclusions

The first conclusion to be drawn from the test data is that all configurations of the late model engines in this engine line exhibit emission levels approaching uncontrolled levels of CO on the transient test. These levels are of concern, especially when comparing this engine line to other late model engines without catalysts (Table 8). These other engines exhibit only about 50 percent of the CO emissions from the 350/400-CID engine line.

Several potential causes for the high CO levels can be hypothesized. First, the late model 350/400-CID engines use an "air valve" type 4-barrel carburetor, which has an auxiliary butterfly valve operated by air velocity. The other late model engines (Table 8) use a more conventional 4-barrel carburetor. It can be hypothesized that under transient heavy loads, the mixture control and distribution of the "air valve" carburetor's secondary circuit or possibly the overall control of the secondary circuit may not be as good as the secondary circuit in the conventional carburetor. Evidence supporting this hypothesis can be found by comparing the transient and 9-mode CO test results of the 1979 350-CID heavy-duty engine in the certified configuration (Table 2) to the results of the other current technology engines (Table 8). The 9-mode CO results of the 350-CID engine are slightly lower than the CO levels of other engines. Yet, when these engines are exercised transiently, as in the real world, over the transient test cycle, the CO of the 350-CID engine becomes nearly double that of the other engines. This pattern of high CO appears to be followed by the LDT 400-CID engine (Table 2) which also has an "air valve" (Table 3) carburetor.

Another possible cause for the high CO on the late model 350- and 400-CID engines could be lack of sufficient air flow capacity in the AIR system. The lack of oxygen is certainly a factor in the CO reduction on the 9-mode for the modified 400-CID catalyst-equipped LDT engine (Table 3). But, further investigation

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1/ EPA Technical Report, "Selection of Transient Cycles for Heavy-Duty Vehicles," HDV 78-02, June, 1978.

2/ Federal Register, Vol. 44, No. 31, February 13, 1979 Proposed Gaseous Emission Regulations - 1983 and Later Model Year Heavy-Duty Engines, Subpart N, §86.1344.

shows that both the 1979 350-CID HD engine and the AIR system added to the 400-CID engine are nearly identical (pump calibration, diverter valve, calibration, and pulley ratio) to the AIR system on the 1979 454-CID engine. Yet, the 454-CID engine exhibits less than half the level of CO (Table 8) emitted by the 350- and 400-CID engines. It seems unlikely that this AIR system could supply sufficient air flow for a 454-CID engine and not supply sufficient air flow for a 350- or 400-CID engine. Therefore, lack of air flow, although not totally discounted, does not appear to be a major factor in the high CO levels.

In contrast to the CO reductions shown on the transient test, HC reductions tended to be rather significant (60-90%). However, even though the transient HC reductions tended to be significant, the 9-mode test still overestimated the transient emission reductions by 10-30%.

Another point of interest about the data from this engine line is that correlation for both HC and CO between the transient test and the 9-mode test can be obtained. Unfortunately, this correlation (Table 9) is not meaningful in an engineering context. It is true for this engine line that lower HC and CO emissions on the 9-mode procedure produce lower transient emission results. But for instance, even when the 9-mode CO emissions are totally eliminated (i.e., intercept = 0), the correlation line would predict over 100 g/bhp-hr of CO on the transient test (Table 10). At the estimated 90 percent reduction standard of 1.3 g/BHP-hr HC and 15.6 g/BHP-hr CO, both of the predicted 9-mode values (HC and CO) would be negative, -0.7 g/BHP-hr HC, and -268 g/bhp-hr CO, totally meaningless numbers. Therefore, it can be said for this engine line in the configurations tested, there is no 9-mode HC or CO result that would correlate to a 90% reduction in real world emissions.

A final point worthy of discussion is the relation of the derived grams per mile on the HD transient test to the grams per mile of the LDT tests (Table 8). While it is recognized that the heavy-duty test does load the engine more than the LDT test, the test data almost indicates that for power levels at some point above the loads imposed during the LDT test procedure, the 1979 LDT engine is nearly uncontrolled for CO emissions.

Two facts bear on the impact on ambient air quality by LDTs: 1) the apparent sensitivity of the LDTs to load; and 2) the Federal Emission Compliance Procedure tests LDTs at a weight approximately equal to empty weight. If the compliance procedure loads LDTs in a representative manner, then the sensitivity to load is of little concern. However, if the compliance procedure does not load the vehicles in a manner representing in-use loading, then the emission sensitivity to load becomes a very real concern. Based on the potential adverse air quality impact if the latter case is true, the authors think the representativeness of the LDT test loads should be reexamined.

Table 1

Description of Engines Tested

Engine #	MY	CID	USE	HP	RPM	AECD	MOD	CARBURETOR	GOVN
BLT8	1969	350	HD	180	3798	None	--	2 Barrel	Yes
BLT11	1969	350	HD	166	3609	None	--	2 Barrel	Yes
CTE6	1979	350	HD	136	3198	Air	--	4 Barrel	No
PCTE6*	1979	350	MOD	136	3198	Air	OC	4 Barrel	No
CTE3	1979	400	LDT	183	3742	EGR/OC/EFE	--	4 Barrel	No
PCTE3**	1979	400	MOD	179	3579	EGR/OC/EFE	AIR	4 Barrel	No

Notes:
AIR = air injection system.
EFE = early fuel evaporation system.
EGR = exhaust gas recirculation system.
OC = oxidation catalyst.

 * Same engine as CTE6
** Same engine as CTE3

Table 2

Comparison of 1969 Engine Emission Results to Emissions Results of 1979 Engines in Their Certified Configurations (Grams/BHP-HR)

Engine #	MY	CID	USE	Transient			9-Mode		
				HC	CO	NOx	HC	CO	NOx
BLT8	1969	350	HD	9.57	169.70	4.70	11.05*	182.50*	3.68*
BLT11	1969	350	HD	6.21	126.13	5.36	7.25	131.47	4.21
CTE6	1979	350	HD	3.14	118.07	6.23	.79	14.62	7.83
CTE3	1979	400	LDT	2.21	131.81	2.32	.81	45.91	2.59
Manufacturer Results**									
CTE6	1979	350	HD	--	--	--	.770	13.17	5.89

* CT mode determined from BLT11
** Raw emission measurements per 40 CFR 86, Subpart D

Table 3

Effect of Modifications to 1979 Engines (Grams/BHP-HR)

Engine #	MY	CID	USE	Transient HC	Transient CO	Transient NOx	9-Mode HC	9-Mode CO	9-Mode NOx
Certified Configuration									
CTE6	1979	350	HD	3.14	118.07	6.23	.79	14.62	7.83
CTE3	1979	400	LDT	2.21	131.80	2.32	.81	45.91	2.59
Modified Configuration									
PCTE6*	1979	350	MOD	2.29	89.57	5.96	.21	.18	7.42
PCTE3**	1979	400	MOD	1.00	99.24	2.38	.06	2.46	2.76

* Same engine as CTE6
** Same engine as CTE3

Table 4

Brake Specific Emission Reductions
as a Percentage of Average 1969 350-CID Emissions

Engine #	MY	CID	USE	Transient BSHC	Transient BSCO	Transient BSNOx	9-Mode BSHC	9-Mode BSCO	9-Mode BSNOx
I. Average 1969 Emission Levels (g/BHP-HR)									
BLT8	1969	350	HD	9.57	169.70	4.90	11.05*	182.50*	3.68*
BLT11	1969	350	HD	6.21	126.13	5.36	7.25	136.47	4.18
AVERAGE				7.89	147.92	5.13	9.15	156.99	3.93
II. Certified Configuration (% Reduction)									
CTE6	1979	350	HD	60.2%	20.2%	-21.4%	91.4%	90.7%	-99.2%
CTE3	1979	400	LDT	72.0%	10.9%	54.8%	91.2%	70.8%	34.1%
III. Modified Configuration (% Reduction)									
PCTE6**	1979	350	HD	71.0%	39.4%	-16.2%	97.7%	99.9%	-88.8%
PCTE3***	1979	400	LDT	87.3%	32.9%	53.6%	99.3%	98.4%	29.8%

* CT mode determined from BLT11

** Same engine as CTE6

*** Same engine as CTE3

Table 5

Brake Specific Emission Reductions as a Percentage of the 1969 Baseline***

Engine #	MY	CID	USE	Transient BSHC	Transient BSCO	Transient NOx
I. 1969 Baseline*** (g/BHP/HR)				12.96	156.03	6.14
Estimated 1983 Standard*** (g/BHP/HP) (i.e., 90% reduction of baseline HC and CO levels)				1.30	15.60	
II. Certified Configuration (% Reduction)						
CTE6	1979	350	HD	75.8	24.3	
CTE3	1979	400	LDT	82.9	15.5	
III. Modified Configuration (% Reduction)						
PCTE6*	1979	350	HD	82.3	42.6	
PCTE3**	1979	400	LDT	92.3	36.4	

* Same engine as CTE6
** Same engine as CTE3
*** Based on engines tested as of 3/15/79 (approximately 75% of the 1969 market represented)

Table 6

Average Brake Specific Fuel Consumption (lb/BHP-HR) Over the Transient Cycle

				Composite	Cold Start				Hot Start			
Engine No.	MY	CID	USE	BSFC	NYNF	LANF	LAF	NYNF	NYNF	LANF	LAF	NYNF
BLT8	1969	350	HD	.659	1.317	.736	.595	.819	.937	.702	.589	.873
BLT11	1969	350	HD	.613	1.743	1.026	.517	.860	.807	.732	.532	.731
CTE6	1979	350	HD	.723	1.488	769	.722	.994	1.054	.760	.635	.805
PCTE6*	1979	350	MOD	.838	1.309	.773	.663	.988	1.055	.788	.853	.832
CTE3	1979	400	LDT	.636	.921	.678	.582	.692	.806	.699	.585	.598
PCTE3**	1979	400	MOD	.687	.912	.722	.633	.763	.863	.761	.646	.663

* Same engine as CTE6
** SAme engine as CTE3

Table 7

Comparison Betweeen LDT Chassis Test Emissions (g/mile) and HD Transient Engine Test Emissions (g/mile)

Engine #	MY	CID	Use	No. of Tests	HC	CO	NOx	MPG
CTE3	1979	400	LDT					
MFG LDT Chassis Test				3	.61	13.87	1.58	10.63*
EPA LDT Chassis Test				3	.73	15.30	1.47	11.20*
EPA HD Engine Test				3	4.09	243.60	4.28	5.28**
CTE6	1979	350	HD					
EPA HD Engine Test				2	4.64	174.52	9.19	5.55**
BLT11	1969	350	HD					
EPA HD Engine Test				3	9.25	189.08	8.02	6.40**
BLT8	1969	350	HD					
EPA HD Engine Test				3	16.41	290.79	8.40	5.43**

* LDT city fuel consumption
** HD composite fuel economy

Table 8

Emission Results from Late Model Engines Tested to Date (1/5/79)
(g/BHP-HR)

Engine #	MY	CID	USE	Transient HC	Transient CO	Transient NOx	9-Mode HC	9-Mode CO	9-Mode NOx
CTE1	1977	391	Cal. HD	2.81	59.02	6.71	--	--	--
CTE2	1979	454	HD	2.26	48.69	6.92	.39	17.33	7.38
CTE4	1978	404	Cal. HD	3.98	54.56	5.01	.63	18.07	5.00
1969 Baseline* (g/BHP-HR)				12.96	156.03				
Estimated 1983 Standard* (i.e., 90% reduction of baseline HC and CO levels)				1.30	15.60				

* Based on engines tested as of 3/15/79 (approximately 75% of the 1969 market represented).

Table 9

Linear Regression of Transient and 9-Mode BSCO Emissions

Engine No.	MY	CID	Use	Transient HC (y)	9-Mode HC (x)	Transient CO (y)	9-Mode CO (x)
BLT8	1969	350	HD	9.57	11.05	169.70	182.50
BLT11	1969	350	HD	6.21	7.25	126.13	131.47
CTE3	1979	350	HD	2.21	0.81	118.07	14.39
PCTE3	1979	350	MOD	1.00	0.06	89.57	185
CTE6	1979	400	LDT	3.14	0.79	131.81	45.94
PCTE6	1979	400	MOD	2.29	0.21	99.24	2.46

Linear Regression: $y = mx + b$	HC	CO
Slope (m)	0.6793	0.322
Intercept (b)	1.7865	102.1713
r^2 =	0.9647	0.7644

Table 10

Emissions Projected from Linear Regression
(g/BHP-HR)

	Transient		9-Mode	
	HC	CO	HC	CO
90% Reduction from Baseline	1.3*	15.6*	-0.7161	-268.60
Zero 9-Mode Emissions	1.786	102.17	0	0

* Based on engines tested as of March 15, 1979.

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