EPA 600-3-84-104

October 1984

CHARACTERIZATION OF HEAVY-DUTY MOTOR VEHICLE EMISSIONS UNDER TRANSIENT DRIVING CONDITIONS

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, N.C. 27711

CHARACTERIZATION OF HEAVY-DUTY MOTOR VEHICLE EMISSIONS UNDER TRANSIENT DRIVING CONDITIONS

by

Mary Ann Warner-Selph
Harry E. Dietzmann
Southwest Research Institute
6220 Culebra Road
San Antonio, Texas 78284

Contract No. 68-02-3722

Project Officer
Frank M. Black
Emissions Measurement and Characterization Division
Environmental Sciences Research Laboratory
Research Triangle Park, N.C. 27711

ENVIRONMENTAL SCIENCES RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, N.C. 27711

NOTICE

This document has been reviewed in accordance with U.S. Environmental Protection Agency policy and approved for publication. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

ABSTRACT

The objective of this program was to characterize heavy-duty diesel truck and bus emissions produced during transient driving cycles. In the initial phase of the program an improved road-load simulation method was developed for use in operating large trucks on a chassis dynamometer. This method was used in testing vehicles on the chassis dynamometer in the latter parts of the program. The second phase of testing involved operation of six vehicles on the chassis dynamometer (over the chassis version of the heavy-duty transient cycle), removal of the engine and testing of the engines (over the heavy-duty engine transient cycle). Chassis emissions were then compared to engine emissions. Additionally, chassis tests were conducted over a range of dynamometer inertia settings for two of the six vehicles for the purpose of comparison with engine emissions. Baseline emissions were also measured on six buses, five single-axle tractors, and 17 dual-axle tractors over the chassis version of the transient cycle. Regulated emissions and several unregulated emissions were measured on baseline tests. Unregulated emissions included particulate, aldehydes and ketones, phenols, DOAS odor, various elements, nitropyrenes, and Ames mutagenic response.

CONTENTS

FIGURES

FIGURES (Cont'd)

FIGURES (Cont'd)

TABLES

TABLES (Cont'd)

TABLES (Cont'd)

SECTION 1

INTRODUCTION

This program was initially divided into five tasks. Task 1 involved developing chassis dynamometer simulation of road load horsepower for truck tractor-trailers and buses. The purpose of Task 2 was to establish the comparability of engine and chassis dynamometer procedures. Task 3 involved emissions testing of a variety of buses and single-axle and dual-axle truck tractors over a chassis version of the transient emissions test. Task 4, which involved testing with additional fuels, was deleted, and that work effort was redirected into the testing of additional vehicles in Task 3. The final report was prepared in Task 5.

OBJECTIVES

The objective of Task 1 was to determine the appropriate amount of power to be absorbed by a chassis dynamometer to simulate on-road driving of trucks and buses. Appropriate road load horsepower simulation is important for meaningful emissions evaluations on a chassis dynamometer.

The objectives of Task 2 were to determine the repeatability of HC, CO, CO_2, NO_x, and particulate emissions in chassis cycle and engine cycle tests and whether there is a correlation between engine cycle and chassis cycle emissions. This task involved five sets of tests with four vehicles over a chassis version of the transient cycle for heavy-duty vehicles and with their respective engines over the 1984 transient test for heavy-duty diesel engines.

The objective of Task 3 was to measure HC, CO, CO_2, NO_x, particulate, and several unregulated emissions during chassis testing of single-axle and dual-axle tractors and buses. Unregulated emissions analyses included aldehydes and ketones, DOAS odor, various elements, organic solubles, and nitropyrenes. In addition, Ames bioassay analyses were performed on organic solubles samples.

Also, in Task 3, two vehicles were operated over a range of dynamometer inertia settings. The purpose of these tests was to determine if a better correlation between chassis cycle and engine cycle emissions could be established by varying chassis inertia weight settings. The engines were then removed and tested over the engine transient cycle.

SCOPE

The work performed in Task 1 involved three vehicles, a city bus, a single-axle truck tractor, and a dual-axle truck tractor. Coastdowns were conducted on the road for each vehicle under essentially ideal weather conditions (primarily no wind) and with zero road grade. Coastdowns were also conducted on the chassis dynamometer with the single-axle tractor and the bus. Results of these determinations, along with data reported in the literature, were used to determine the power to be absorbed by a chassis dynamometer.

Task 2 involved testing of four vehicles, a city bus with a 1982 Detroit Diesel 6V-71, two dual-axle tractors, one with a 1980 Cummins Formula 350 and one with a 1980 Detroit Diesel 8V-92TA, and a single-axle tractor equipped with a 1979 IHC DT-466. Each of the vehicles was tested using a chassis version of the transient cycle over five tests. The engine from each of these vehicles was removed and installed on the engine dynamometer and tested using the 1984 engine transient procedure for diesel engines over five tests. Regulated emissions (HC, CO, CO_2, and NO_x) and particulate were measured for all chassis and engine transient tests. The city bus was tested using a DF-1 Emissions Test Fuel (EM-400-F) and the three tractors were tested with a DF-2 Certification Fuel (EM-528-F).

Task 3 involved testing of five buses, four single-axle tractors, and 15 dual-axle tractors over the chassis version of the transient cycle. Each vehicle was operated over a minimum of two duplicate transient cycles. The buses were tested with a DF-1 Emissions test Fuel (EM-455-F), and the tractors were tested with a DF-2 Certification Fuel (EM-528-F).

Two vehicles, one with an audit engine which had been previously tested, were obtained and tested using the chassis and the engine test procedures. Chassis testing was conducted over a range of dynamometer inertia settings to determine if emissions measured at another inertia setting would better correlate with emissions obtained in the engine transient test.

Several changes in the scope of work were made during the course of the program at the request of the project officer. Fuel consumption determinations were expanded to include Flo-tron fuel measurements, in addition to the carbon balance method. Continuous measurement of NO_x was added beginning with Vehicle 3-5. Previously, NO_x was measured in Tedlar bags only. An improved method for the analysis of aldehydes and ketones was adopted beginning with Vehicle 3-8. The measurement of various elements in exhaust and the operation of two vehicles over both chassis and engine cycles were added to Task 3.

In addition to regulated emissions, Task 3 also included measurement of several unregulated emissions. Aldehydes and ketones, and phenols were sampled via impinger methods and analyzed by liquid and gas chromatography, respectively. Odor samples were collected on Chromosorb traps and analyzed on the Diesel Odor Analysis System (DOAS). Particulate samples were sent to EPA-RTP for elemental x-ray analyses. Organic solubles were extracted from 20x20 inch particulate filters using methylene chloride. A portion of the extractables was analyzed for nitropyrenes using a liquid chromatograph. Ames bioassay was performed on the remaining portion of extractables at Southwest Foundation for Biomedical Research, formerly Southwest Foundation for Research and Education.

SECTION 2

CONCLUSIONS

This program involved an investigation of emissions from heavy-duty engines and vehicles under transient cycle operation. Vehicles evaluated included single-axle truck tractors, dual-axle truck tractors, and city buses.

Initially, an improved chassis dynamometer simulation of road load horsepower was developed. The subsequent emissions evaluations included: engine transient cycle tests, vehicle transient cycle tests, reduced chassis dynamometer horsepower settings, effect of inertia, and selected unregulated emissions.The initial phase involved developing an improved dynamometer simulation of road power for truck tractor-trailers and buses. Analytical and experimental studies were performed to mathematically determine, under essentially ideal environmental conditions, truck or bus power-speed characteristics. The "coastdown" method (time to decelerate from one speed to a lower speed) was used to compute road horsepower. From the road evaluations, a generalized expression for determining road horsepower at various vehicle speeds was developed.

To determine the chassis dynamometer power settings for a vehicle, the road horsepower is calculated using the vehicle weight and frontal area. Then, the power absorbed by the vehicle drive train and tires, the dynamometer bearings, and the tire and inertia system windage is determined by coastdowns of the vehicle on the dynamometer. This absorbed power is then subtracted from the calculated total power required on-the-road, to determine the power values for the controllable power absorption unit on the chassis dynamometer.

A major finding of the study was the significant effect that non-ideal environmental conditions have on road-power. Side winds are especially significant, and merely operating the vehicle in opposite directions over a level course does not cancel out these effects. From data obtained with side winds present, it appears that the use of ideal conditions (i.e., no wind, etc.) results in horsepower values that are ten to fifteen percent lower for tractor-trailer trucks at half payload. Results from this phase of the study were reported in an SAE paper.(1)*

The second phase involved the evaluation of six vehicles over a heavy-duty chassis transient cycle with subsequent removal of the engines for evaluation over the heavy-duty engine transient cycle. The emissions results were compared to determine if there was a correlation between engine and chassis cycle emissions. Using an EPA assigned engine transient equivalent distance of 10.3 km, chassis cycle HC emissions exceeded engine cycle HC by 10 to 30 percent and chassis cycle particulate emissions were 18 to

*Numbers in parentheses designate references at the end of the report.

28 percent greater than engine cycle particulate emissions. CO emissions from chassis and engine cycle tests were more variable, with chassis cycle CO ranging from 48 percent lower to 27 percent higher than engine cycle CO. NO_x values from chassis cycle tests were in relatively close agreement with engine cycle NO_x, on the average, within 11 percent. The one exception to the preceding emissions values was a city bus powered by a 1982 Detroit Diesel 6V-71 engine. With this bus, the CO, NO_x, and particulate emissions in the chassis cycle test were approximately twice as high as in the engine cycle test.

When the engine and chassis comparisons are based on a fuel specific basis, the agreement is generally improved. Fuel specific emission rate comparisons eliminate the uncertainty associated with the extrapolation of engine data to g/km. For one engine, the DD 8V-92TA, the 10.3 km was probably close to true engine operation since good agreement was achieved for g/km and g/kg fuel. For two vehicles, powered by an International Harvester DT-466B and a Cummins Formula 350, emissions are in noticeably better agreement when making comparisons on a fuel specific basis rather than g/km. Comparison of engine and chassis emissions from a city bus (DD 8V-71) illustrated virtually no agreement for either fuel specific or g/km, although fuel specific chassis and engine emission rates were closer.

Two of the vehicles, a single-axle tractor and a dual-axle tractor, were evaluated at several inertia settings. In general, CO, CO_2, NO_x, and particulate chassis emissions increased as dynamometer inertia was increased. Chassis HC remained relatively constant over the range of inertia settings used. Trends in the chassis and engine emissions data are summarized in Table 1.

The dual-axle tractor was also tested at reduced horsepower (80 percent of standard horsepower) to compare the emissions measured at standard horsepower to emissions measured at reduced horsepower. In general, CO, CO_2, NO_x, and particulate emissions from tests conducted at 80 percent of standard horsepower were 5 to 12 percent lower than at standard horsepower. HC emissions did not appear to be significantly different at the two horsepower settings tested.

The fourth phase of testing was a baseline evaluation of emissions at 70 percent of GVW from buses, dual-axle tractors, and single-axle tractors. Six buses, 17 dual-axle tractors, and five single-axle tractors were operated over a chassis version of the transient cycle. Five of the buses were also tested over a New York Bus Cycle. The overall average regulated emissions and particulate results are summarized in Table 2. Average HC emissions measured over the chassis transient cycle were nearly equivalent for buses and dual-axle tractors, while HC from single-axle tractors was slightly higher. CO and particulate emissions were lowest from single-axle tractors and highest from buses tested over the chassis transient cycle. CO_2 and NO_x emissions were also lowest from single-axle tractors and highest from dual-axle tractors. HC, CO, CO_2, NO_x and particulate emissions were generally higher with buses tested over the New York Bus Cycle than the chassis transient cycle.

TABLE 1. COMPARISONS OF ENGINE AND CHASSIS TRANSIENT CYCLE TESTS[a]

Emission[a]	Single-Axle (Vehicle 3-23)[b]	Dual-Axle (Vehicle 3-24)[c]
HC	Engine transient cycle understates HC at all inertia settings	Engine transient cycle understates HC at all inertia settings
CO	Engine transient cycle overstates CO at all inertia settings	Engine and chassis cycle CO correlate at 91 percent of GVW
CO_2	Engine transient cycle overstates CO_2 at all inertia settings	Engine and chassis cycle CO_2 correlate at 68 percent of GVW
NO_x	Engine transient cycle overstates NO_x at all inertia settings	Engine and chassis cycle NO_x correlate at 78 percent of GVW
Part.	Engine transient cycle understates particulates at all inertia settings	Engine and chassis cycle particulate correlate at 57 percent of GVW

[a]Emissions comparison based on emission rates in g/km.
[b]Chassis cycle tests conducted at inertia settings of 61%, 70%, 80% and 93% of GVW.
[c]Chassis cycle tests conducted at inertia settings of 55%, 70%, 86% and 97% of GVW.

TABLE 2. EMISSIONS MEASURED OVER THE CHASSIS TRANSIENT CYCLE AND NEW YORK BUS CYCLE

		Emission Rate, g/km				
Vehicle Type	Cycle[a]	HC	CO	CO_2	NO_x[b]	Part.
Buses	CTC	1.7	27	1235	12	2.5
Dual-Axle Tractors	CTC	1.7	7	1465	17	1.5
Single-Axle Tractors	CTC	1.9	4	1055	9	1.1
Buses	NYBC	2.2	48	1490	15	3.9

[a]Chassis version of the transient cycle and New York Bus Cycle
[b]NO_x from bag measurement

Fuel consumption for chassis and engine testing was determined by the carbon balance method and by direct measurement using a Flo-tron. Measured fuel consumption was greater than calculated fuel consumption for all three vehicle types tested. Measured values were 5 to 12 percent higher than calculated fuel consumption for buses, 4 to 8 percent higher for single-axle tractors, and 0 to 4 percent higher for dual-axle tractors. By vehicle group, fuel consumption was lowest for single-axle tractors and highest for dual-axle tractors.

NO_x was measured continuously and in bags for 19 of the vehicles. Overall, continuous NO_x emissions were about seven percent higher than bag NO_x emissions, and NO_x measured by the two methods differed by as much as 24 percent.

Selected unregulated emissions were also measured during chassis testing. These included aldehydes and ketones, phenols, DOAS odor, various elements, and nitropyrenes. In addition, Ames bioassay analyses were performed on organic extractables from particulate samples. Generally, phenols were not detected at significant levels from any of the vehicles tested.

The most prevalent aldehydes and ketones found in dilute exhaust were formaldehyde, acetaldehyde, and acetone. Formaldehyde concentrations ranged from 10 to 250 mg/km, acetaldehyde was found at levels up to 203 mg/km, and acetone at levels up to 87 mg/km. Formaldehyde made up 26 to 56 percent of total aldehydes and ketones emitted from dual-axle tractors, 31 to 59 percent of total aldehydes and ketones from buses, and about 33 percent of total aldehydes and ketones from single-axle tractors.

Odor was measured on the Diesel Odor Analysis System (DOAS) as LCA (aromatics) and LCO (oxygenates). Most of the vehicles produced higher concentrations of LCA than LCO. As a group, buses produced the highest LCA and lowest LCO levels. Single axle tractors produced the lowest LCA, while dual-axle tractors produced the highest LCO.

Of the 31 elements analyzed, only phosphorus and sulfur were found in measurable levels for all the vehicles evaluated. Chlorine, potassium, magnesium, and iron were emitted by several of the test vehicles at or above the minimum detection limits.

Organic extractable samples of particulate were analyzed for 1-nitropyrene and three dinitropyrenes. No dinitropyrenes were found in measurable quantities, while 1-nitropyrene was found in concentrations ranging from 1 to 17 micrograms/km. Nitropyrene emissions were highest from single-axle tractors and lowest from buses.

Ames bioassay analyses were performed on organic extract samples using three tester strains (TA1538, TA98, and TA100), both with and without metabolic activation (S9). The most sensitive tester strain to the extracts was TA100 without metabolic activation, and the least sensitive was TA1538. Ames response in revertants/km was highest for single-axle tractors and lowest for buses.

SECTION 3

RECOMMENDATIONS

Results reported in this study have provided an important step forward in understanding the relationship between engine and chassis testing, as well as providing a significant data base for the characterization of heavy-duty trucks and buses for gaseous, particulate and unregulated emissions. Upon completion of this program, it was apparent many areas of investigation remain, before the knowledge of heavy-duty truck and bus emissions approach that of the automobile. Several of the areas suggested for additional research are briefly described by various vehicle categories.

CITY BUSES

Engine versus chassis comparisons of a city bus showed virtually no agreement of gaseous or particulate emissions. Additional work is recommended to include engine versus chassis comparisons on a different bus with the same engine model. This study should include the engine bus transient cycle (a cycle not available at the time of this study) as well as several inertia weights during chassis testing.

Additional buses should be included that would expand the data base to include the DD 6V-92TA and Cummins V-903 engines, and other engines representing significant fractions of the bus population. These evaluations should include both chassis and engine testing for these engines. Consideration should be also given to developing a different bus cycle, if it is felt that the current cycle is not representative of real life bus operation.

DUAL-AXLE DIESEL TRUCK TRACTORS

This program generated a substantial amount of emissions characterization from a variety of dual-axle tractors. These vehicles basically represent engine production from 1979-1981. Although most of the major engine models were included in this study, there will undoubtedably be new models introduced each year. In order to keep current on in-use emissions characterization of heavy-duty vehicles, it is suggested that EPA continue a limited amount of characterization to include new technology engines that will be built to meet the particulate standards.

Several factors influence the gaseous and particulate emissions from a given engine in a dual-axle truck. The influence of inertia weight on emissions was investigated in this study, but this was only a first step in understanding the relationship between chassis and engine emission results. For example, how much does the transmission and gear train affect emissions, do the tires influence emission results, do assumptions in frontal area significantly affect emissions from dual-axle tractor. Many of the questions could be answered by obtaining two vehicles with identical engines, but different drive trains, tires, etc.; testing the vehicles over the chassis cycle; then removing the engine and testing them over the engine transient cycle. Upon completion, the engines would be switched from their original chassis and the chassis testing repeated. This would provide information to determine if assumptions made during chassis testing significantly affect emissions as well as expand the data base for engine chassis comparisons. In addition, hot-start evaluations would be conducted at several horsepower settings and inertia weights to further assess the effects of these parameters.

SINGLE-AXLE DIESEL TRUCK TRACTORS

Results of two engine-chassis comparisons were obtained in this study. In one case (IHC DT-466B), good agreement was observed, but in the other case (Cummins NTC-300), virtually no agreement between chassis and engine emissions was observed. In the case where good agreement was observed, the engine power to vehicle weight appeared to be more "normally" matched for a single-axle truck tractor. In the case of the second engine with virtually no agreement in emission results, the Cummins NTC-300 engine had a relatively high power to vehicle weight ratio. Several of the single-axle tractors had engines with relatively high power to vehicle weight ratios. The Cummins NTC-300 engine in a dual-axle tractor would probably provide a better agreement of chassis and engine emission results. If it is felt that a significant fraction of the single-axle, truck tractor population is in this category, then additional work would be warranted. This work could be similar to that described earlier, with a given engine model (e.g., Cummins NTC-300) being used in both single- and dual-axle tractors for chassis testing. This engine would also be tested over the engine transient cycle. The chassis tests should include various horsepower settings to simulate different frontal areas and different inertia weights to simulate different loadings.

Additional emissions characterization is also in order for single-axle tractors to include engines that were not available for this study and possibly include Class VI diesel vehicles. As the technology for developing low particulate heavy-duty diesel engines becomes available, it is suggested that EPA continue the characterization study at a low-level of effort.

HEAVY-DUTY GASOLINE VEHICLES

In-house studies in progress at EPA in Research Triangle Park are addressing heavy-duty gasoline vehicles requiring inertia up to about 19,000 lbs. A significant portion of the heavy-duty gasoline vehicles are above 19,000 lbs and will not be included in that study. Only a limited amount of chassis testing on heavy-duty gasoline vehicles has been conducted using the transient cycle; and even less data exists on engine versus chassis comparisons. In general, heavy-duty gasoline chassis tests have not included unregulated emissions characterization. The virtual lack of emissions data in the heavy-duty gasoline vehicle category suggest that additional work in this area may be justified. Some vehicle categories that would be good candidates would include school buses, large box vans and soft drink and beer delivery trucks.

SECTION 4

GENERAL EQUIPMENT, INSTRUMENTS, AND PROCEDURES

VEHICLE DESCRIPTION

Four vehicles were tested in Task 2 of this program and 24 vehicles were tested in Task 3. Descriptions of test vehicles are given in Table 3. Task 2 vehicles were numbered 2-1, through 2-4, and Task 3 vehicles were numbered consecutively from 3-1 through 3-24. A total of five single-axle tractors, 17 dual-axle tractors, and 6 buses were tested. One single-axle tractor and one dual-axle tractor were powered by audit engines which had been previously tested.

Chassis dynamometer parameters used in vehicle testing are given in Tables 4, 5, and 6 for single-axle tractors, dual-axle tractors, and buses, respectively. The tables include test inertia, weight on dynamometer rolls, and dynamometer horsepower settings at 50 mph. Horsepower, which had been determined by performing coastdowns on the dynamometer, was used in this study. The calculations for this procedure are described in Appendix A.

TABLE 4. DYNAMOMETER PARAMETERS FOR SINGLE-AXLE TRACTORS[a]

Vehicle	Engine Description	Test Inertia, lbs	Weight on Dyno Rolls, lbs	EPA Dyno Setting at 50 mph, hp	Coastdown Dyno Setting at 50 mph, hp
2-4	1979 IH DT-466	29,000	7550	75.7	61.8
3-1	1978 Cummins Form. 350	29,000	9500	70.8	52.8
3-2	1979 IH DT-466	29,000	7490	75.9	72.3
3-3	1977 Cummins Form. 290	29,000	8730	72.8	65.8
3-23	1981 Cummins NTC-300[b]				
	70% of GVW	29,000	8250	72.6	43.3
	61%	25,500	8250	68.3	41.3
	93%	38,500	8250	84.5	53.6
	80%	33,000	8250	77.6	49.7

[a]GVW of a single-axle tractor with a single-axle trailer is 41,500 lbs.
[b]Vehicle 3-23 tested at reduced horsepower, 80 percent of standard

TABLE 3. VEHICLE DESCRIPTION

Task	Vehicle	Chassis Description	Cab[a]	Unit Description	Odometer	Engine Description Year	Manufacturer	Model
2	1	GMC RTS II	—	VIA City Bus 360	95000	1980	Detroit Diesel	6V-71N
2	2	White Freightliner	COE	Dual Axle Tractor	38000	1980	Cummins	Formula 350
2	3	IHC Transtar II	COE	Dual Axle Tractor	32600	1980	Detroit Diesel	8V-92TA
2	4	IHC S-2100	CON	Single Axle Tractor	104850	1979	Int'l Harvester	DT-466B
3	1	Peterbilt	COE	Single Axle Tractor	70455	1978	Cummins	Formula 350
3	2	Int'l Harvester	CON	Single Axle Tractor	59676	1979	Int'l Harvester	DT-466
3	3	IHC Transtar II	COE	Single Axle Tractor	215790	1977	Cummins	Formula 290
3	4	IHC Transtar II	COE	Dual Axle Tractor	79616	1980	Detroit Diesel	8V-92TA
3	5	IHC Transtar II	COE	Dual Axle Tractor	238577	1979	Detroit Diesel	8V-92TA
3	6	White Freightliner	COE	Dual Axle Tractor	261000	1979	Cummins	NTC-400
3	7	White Freightliner	COE	Dual Axle Tractor	78875	1981	Cummins	Formula 350
3	8	GMC RTS II	—	VIA City Bus 356	163732	1980	Detroit Diesel	6V-71N
3	9	GMC RTS II	—	VIA City Bus 382	182119	1980	Detroit Diesel	6V-71N
3	10	Mack	CON	Dual Axle Tractor	221936	1981	Mack	EM6-285R
3	11	Mack	CON	Dual Axle Tractor	240732	1980	Mack	EM6-285
3	12	Kenworth	COE	Dual Axle Tractor	100000	1976	Caterpillar	3406 Economy
3	13	Kenworth	COE	Dual Axle Tractor	180216	1982	Caterpillar	3406
3	14	White Freightliner	COE	Dual Axle Tractor	57755	1982	Cummins	Formula 350
3	15	Transtar II	COE	Dual Axle Tractor	176000	1979	Cummins	Formula 350
3	16	Transtar 4300	CON	Dual Axle Tractor	147867	1979	Cummins	NTC-290
3	17	Kenworth	COE	Dual Axle Tractor	158740	1981	Cummins	Formula 350
3	18	Ford 900	CON	Dual Axle Tractor	33602	1981	Cummins	NTC-300
3	19	GMC Brigadier	CON	Dual Axle Tractor	81878	1980	Cummins	NTC-300
3	20	GMC RTS II	—	VIA City Bus 349	137000	1980	Detroit Diesel	6V-71N
3	21	Chance RT-50	—	VIA Mini Bus 112	139173	1979	Caterpillar	3208
3	22	GMC RTS II	—	VIA City Bus 307	246988	1978	Detroit Diesel	8V-71N
3	23	IHC CO9670	COE	Single Axle Tractor	266541	1981	Cummins	NTC-300
3	24	IHC Transtar II	COE	Dual Axle Tractor	177000	1980	Detroit Diesel	8V-92TA

Test Number Example

2 1 1 2 E

- E designated engine tests (no letter indicates chassis)
- Test Number 2
- Fuel Number 1 (Fuel 1 = DF-1 Emissions Test Fuel, Fuel 2 = DF-2 Phillips Reference, Fuel 3 = No. 1 Emissions Test Fuel)
- Vehicle Number 1
- Task 2

[a] COE designates cab-over-engine and CON designates conventional cab

TABLE 5. DYNAMOMETER PARAMETERS FOR DUAL-AXLE TRACTORS[a]

Vehicle	Engine Description	Test Inertia, lbs[b]	Weight on Dyno Rolls, lbs	EPA Dyno Setting at 50 mph, hp	Coastdown Dyno Setting at 50 mph, hp
2-2	1980 Cummins Form. 350	54,000	10,700	89.8	87.0
2-3	1980 DD8V-92TA	54,000	11,100	87.8	58.2
3-4	1980 DD8V-92TA	54,000	10,990	87.5	62.0
3-5	1979 DD8V-92TA	54,000	11,160	87.1	79.1
3-6	1979 Cummins NTC-400	54,000	10,910	87.7	68.6
3-7	1981 Cummins Form. 350	54,000	10,720	88.2	82.4
3-10	1981 Mack EM6-285R	54,000	12,070	84.8	81.1
3-11	1980 Mack EM6-285	54,000	12,160	84.6	76.6
3-12	1976 Cat. 3406 Economy	54,000	12,040	84.9	77.4
3-13	1982 Cat. 3406	54,000	12,380	84.0	58.6
3-14	1982 Cummins Form. 350	54,000	11,520	86.2	73.5
3-15	1979 Cummins Form. 350	57,000	11,240	90.4	65.2
3-16	1979 Cummins NTC-290	54,000	11,670	85.8	80.6
3-17	1981 Cummins Form. 350	54,000	11,620	86.0	68.7
3-18	1981 Cummins NTC-300	57,000	11,950	88.8	85.0
3-19	1980 Cummins NTC-300	57,000	11,570	89.8	70.4
3-24	1980 DD 8V-92TA				
	70% of GVW				
	Std. Hp	54,000	11,100	87.2	80.3
	Red. Hp[c]	54,000	11,100	60.2	52.9
	55% of GVW				
	Std. Hp	42,500	11,100	72.8	66.7
	Red. Hp[c]	42,500	11,100	48.8	47.5
	86% of GVW				
	Std. Hp	67,000	11,100	103.6	91.8
	Red. Hp[c]	67,000	11,100	73.4	62.4
	97% of GVW				
	Std. Hp	75,500	11,100	114.2	96.7
	Red. Hp[c]	75,500	11,100	81.8	68.0

[a] GVW of a dual-axle tractor with a dual-axle trailer ranged from 78,000 to 80,000 lbs.
[b] Test inertia varied with GVW
[c] Reduced horsepower is 80 percent of standard

TABLE 6. DYNAMOMETER PARAMETERS FOR BUSES[a]

Vehicle	Engine Description	Test Inertia, lbs	Weight on Dyno Rolls, lbs	EPA Dyno Setting at 50 mph, hp	Coastdown Dyno Setting at 50 mph, hp
2-1	1980 DD6V-71N	28,300	16,670	25.0	21.6
3-8	1980 DD6V-71N	28,300	16,950	23.8	20.0
3-9	1980 DD6V-71N	28,300	16,970	23.5	25.0
3-20	1980 DD6V-71N	28,300	16,790	24.2	22.9
3-21	1979 Cat. 3208	14,000	7,820	32.8	29.0
3-22	1978 DD8V-71N	28,300	--[b]	--[b]	31.3

[a] GVW of buses ranged from 20,000 to 36,000 lbs.
[b] Bus raised slightly with jacks

FUELS DESCRIPTION

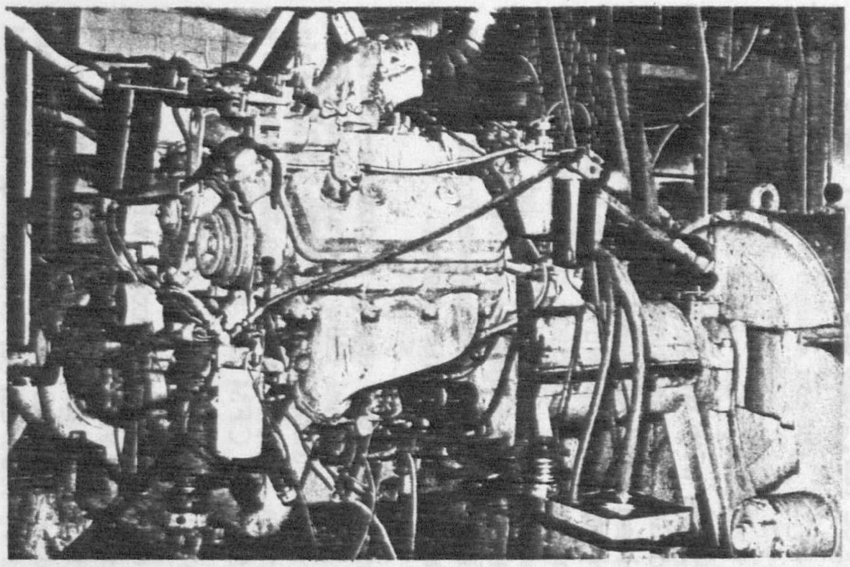
Two diesel fuels were used in this program, DF-1 Emissions Test Fuel for buses and DF-2 certification fuel for tractors. The DF-2 fuel, EM-528-F, was obtained from Phillips Petroleum. The first bus tested, Vehicle 2-1, was operated with DF-1 Emissions Test Fuel EM-400-F (provided by Howell Hydrocarbons) while all subsequent buses, Vehicles 3-8, 3-9, 3-20, 3-21, and 3-22, were tested using DF-1 Emissions Test Fuel EM-455-F from Gulf Oil. Physical properties for the three test fuels are listed in Table 7.

DYNAMOMETERS AND CVS SYSTEMS

Transient engine testing was performed in accord with the 1984 Transient test for Heavy-Duty Diesel Engines.(2) The procedure specifies transient engine operation over variable speed and load, the magnitude of the load depending on the power output capability of the test engine. The cycle requires relatively rapid dynamometer control, that is, the capability to load the engine one moment and motor it the next. The system used in this program consisted of a GE 200 hp motoring/250 hp absorbing dynamometer coupled to a Midwest 500 hp eddy current (absorbing) dynamometer, with a suitable control system fabricated in-house. A photograph of the engine from Vehicle 2-1, a DD 6V-71, installed on the engine dynamometer is shown in Figure 1.

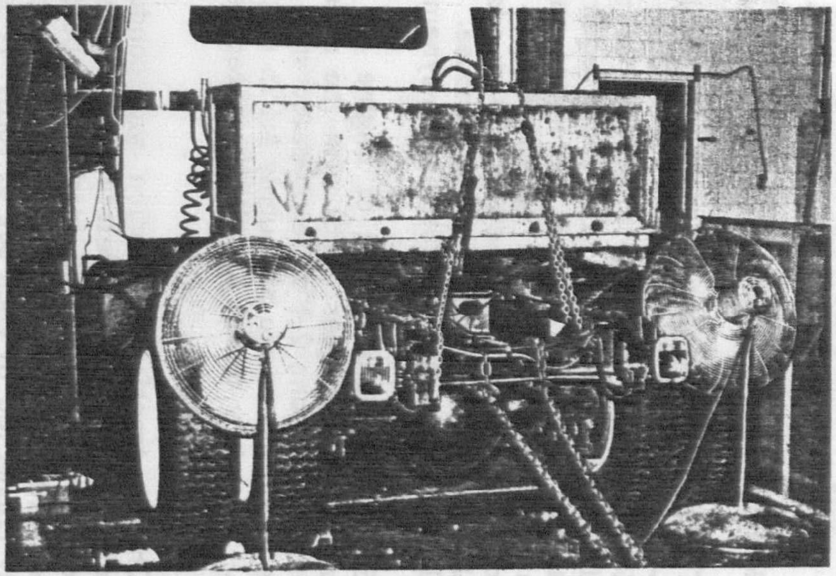
Engine transient testing of Engine 2-1 was conducted using a double-dilution constant volume sampler (CVS) with the main dilution tunnel flow set at 1100 CFM. Engines 2-2, 2-3, and 2-4 were operated with a main dilution flow of 1900 CFM. This provided a dilution ratio of roughly 4:1 in the primary tunnel and 12:1 in the secondary tunnel. Secondary tunnel sample flowrates were about 1 CFM for all engine transient tests.

Chassis transient operation was conducted in general accord with the EPA Recommended Practice for determining exhaust emissions via the chassis version of the Transient Cycle.(3) Vehicle testing was performed on a tandem drive dynamometer equipped with two air-gap 350 hp eddy current power absorbers and with inertia wheels directly connected to each set of rolls. A speed vs load curve, simulating road-load

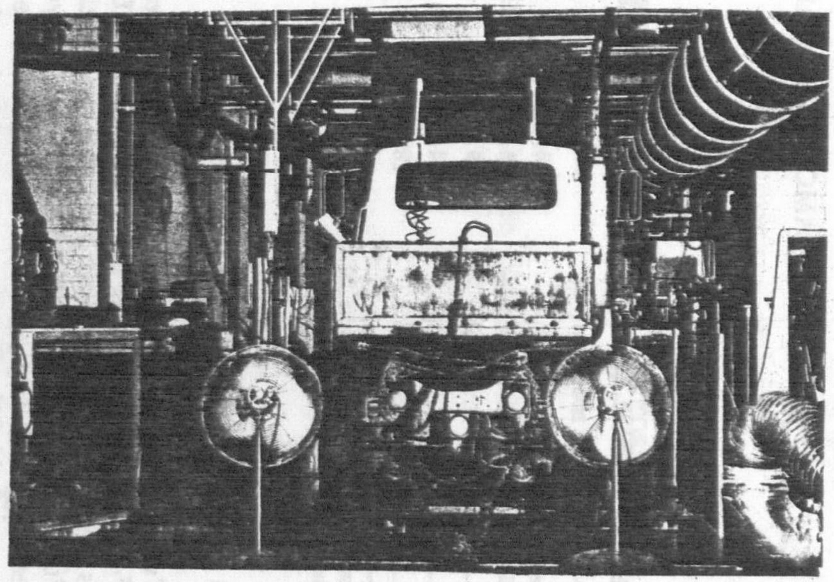


Engine 2-1 DD 6V-71

Vehicle 3-8 City Bus



Vehicle 2-4 Single-Axle Tractor



Vehicle 3-18 Dual-Axle Tractor

Figure 1. Several views of the engine dynamometer, chassis dynamometer, and the CVS tunnel

TABLE 7 . DIESEL FUEL ANALYSIS

	DF-1 Emissions Test Fuels		DF-2 Certification Fuel
	EM-400-F	EM-455-F	EM-528-F
Density, g/mℓ	0.812	0.809	0.845
Gravity, °API	42.9	43.0	35.8
Cetane (D-976)	49.0	50.1	47.5
Viscosity, CS (D-445)	1.69	1.7	2.5
Flash Point, °C	70	53	69
Sulfur, wt. % (D-1266)	0.17	0.19	0.22
Gum, mg/100 mℓ (D-381)	4.6	2.4	2.8
Carbon, wt. %	86.37	85.92	86.85
Hydrogen, wt. %	13.54	13.75	13.00
Nitrogen, wt. %	0.006	0.0008	0.01
FIA:			
Aromatics, %	10.5	12.9	29.1
Olefins, %	1.5	3.4	0.9
Saturates, %	88.0	83.9	70.0
Distillation (D-86)			
IBP, °C	190	187	188
10% Point, °C	203	207	217
20% Point, °C	207	210	231
30% Point, °C	209	214	243
40% Point, °C	212	217	253
50% Point, °C	214	219	262
60% Point, °C	217	222	270
70% Point, °C	221	226	278
80% Point, °C	227	231	288
90% Point, °C	238	242	301
95% Point, °C	258	262	311
EBP, °C	293	294	323
Recovery, %	99.0	99.0	99.5
Residue, %	1.0	0.5	0.5
Loss	0	0.5	0

horsepower, was programmed into the system using a load control circuit. This method for determining and setting road load horsepower into the dynamometer was established in Task 1 and is summarized in Appendix A.

A single dilution CVS with maximum capacity of 12,000 cfm was used with vehicles tested on the chassis dynamometer. The CVS was set at flow rates ranging from 4000 to 9000 cfm, depending on engine horsepower and ambient temperature. Table 8 lists the CVS dilution air flow-rates used for vehicle testing. Photographs of a bus (Vehicle 3-8), a single-axle tractor (Vehicle 2-4), and a dual-axle tractor (Vehicle 3-18) on the chassis dynamometer are shown in Figure 1. The CVS tunnel is also shown in the upper right hand side of the photograph of Vehicle 3-18.

DRIVING CYCLES

Vehicle testing involved vehicle operation over three different driving cycles: the 1984 Transient FTP for Heavy-Duty Diesel Engines (2), the "Recommended Practice for Determining Exhaust Emissions From Heavy-Duty Vehicles Under Transient Conditions"(3), and the New York Bus Cycle(4).

The 1984 engine transient cycle is described in the Federal Register by percent of maximum torque and percent of rated speed for each one-second interval, for a test cycle of 1199 seconds duration. This 20-minute transient cycle is composed of four five-minute segments. The four segments are described as follows:

Engine Transient Cycle

Segment	Time, sec
New York Non-Freeway (NYNF)	297
Los Angeles Non-Freeway (LANF)	300
Los Angeles Freeway (LAF)	305
New York Non-Freeway (NYNF)	297

In generating the transient cycle for the engines, an engine power curve was obtained from "minimum to maximum" speed. "Minimum speed" is defined as low idle rpm less 200 rpm, or 400 rpm, whichever is greater. "Maximum speed" is defined as curb idle rpm plus 113 percent of the difference between measured rated rpm and curb idle rpm. The Federal Register specifies that the engine power map begin at 400 rpm. Data from this "power curve", or engine map, was used in conjunction with the specified speed and load percentages to form the transient cycle.

A graphic presentation of resulting speed and torque commands used in an engine transient cycle for a 250 hp diesel engine is given in Figure 2. In this example, the engine had a peak torque of 650 ft-lbs (880 N·m) and a rated speed of 2200 rpm. The negative torque commands provide closed-rack motoring of the engine.

An Engine "Transient FTP Test" consists of a cold-start transient cycle followed by a hot-start transient cycle. For the cold-start, the diesel engine is operated over a "prep" cycle, then allowed to stand overnight at an ambient soak temperature of 20 to 30°C (68° to 86°F). The cold-start transient cycle begins when the engine is cranked for cold start-up. Upon completion of the cold-start transient cycle, the engine is shut

TABLE 8. CONSTANT VOLUME SAMPLER (CVS) DILUTION FLOWRATES

Vehicle Number	Vehicle Description	Dilution Air Flowrate, CFM
2-1	1982 Bus DD6V-71	7000
2-2	1980 Cummins Form. 350	7000
2-3	1980 DD8V-92TA	7000
2-4	1979 IHC DT-466	4000
3-1	1978 Cummins Form. 350	6000
3-2	1979 IH DT-466B	4000
3-3	1977 Cummins Form. 290	6000
3-4	1980 DD8V-92TA	7000
3-5	1979 DD8V-92TA	7000
3-6	1979 Cummins NTC-400	7000
3-7	1981 Cummins Form. 350	7000
3-8	1980 Bus DD6V-71N	7000
3-9	1980 Bus DD6V-71N	7000
3-10	1981 Mack EM6-285R	6000
3-11	1980 Mack EM6-285	6000
3-12	1976 Cat. 3406 Economy	6000
3-13	1982 Cat. 3406	7000
3-14	1982 Cummins Form. 350	8000
3-15	1979 Cummins Form. 350	9000
3-16	1979 Cummins NTC-290	9000
3-17	1981 Cummins Form. 350	9000
3-18	1981 Cummins NTC-300	8000
3-19	1980 Cummins NTC-300	8000
3-20	1980 Bus DD6V-71N	9000
3-21	1979 Bus Cat. 3208	6000
3-22	1978 Bus DD8V-71N	9000
3-23	1981 Cummins NTC-300	6000
3-24	1980 DD8V-92TA	7000

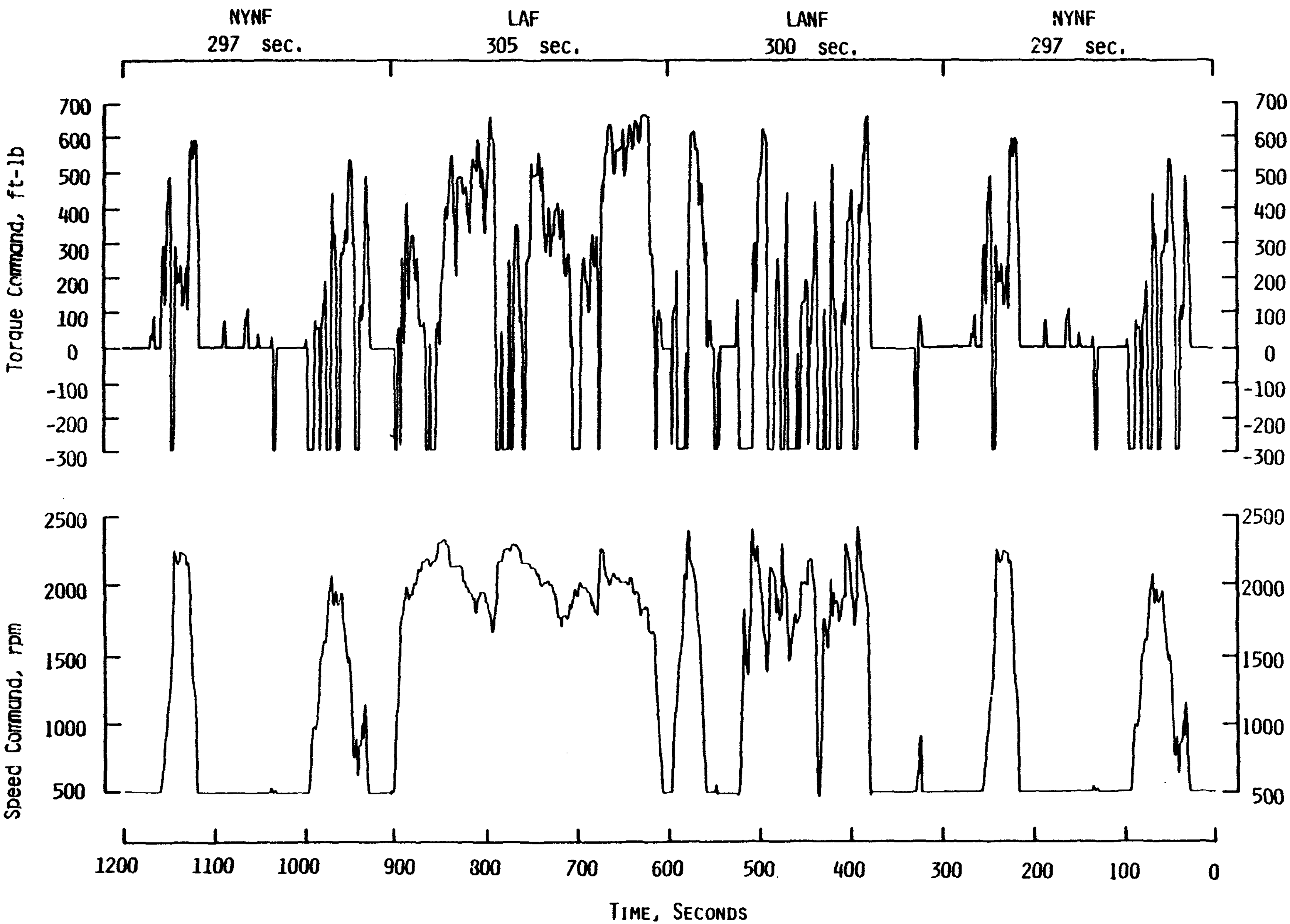


Figure 2. Graphic representation of torque and speed commands for the 1984 Transient cycle for a 250 hp at 2200 rpm diesel engine

down and allowed to stand for 20 minutes. After this hot soak period the hot-start cycle begins with engine cranking.

In order to judge how well the engine follows the transient cycle command, engine responses are compared to engine commands and several statistics are computed. According to the Federal Register, the following regression line tolerances should be met.

REGRESSION LINE TOLERANCES

	Speed	Torque	Brake Horsepower
Standard Error of Estimate (SE) of Y and X	100 rpm	13% of Maximum Engine Torque	8% of Maximum Brake Horsepower
Slope of the Regression Line, M	0.970 1.030	0.83-1.03 Hot 0.77-1.03 Cold	0.89-1.03 (Hot) 0.87-1.03 (Cold)
Coefficient of Determination, R^2	0.9700 1/	0.88 (Hot) 1/ 0.8500 (Cold) 1/	0.9100 1/
Y Intercept of the Regression Line, B	±50 rpm	±15 ft lb	±5.0 brake horsepower

1/ minimum

In addition to these statistical parameters, the actual cycle work produced should not be more than 5 percent above, or 15 percent below, the work requested by the command cycle.

The chassis transient test is composed of a cold-start cycle followed by a 20-minute soak period and then a hot-start cycle. On the day preceding testing the vehicle is prepped by driving through the chassis transient test. The vehicle is then allowed to stand overnight prior to the cold-start. The transient cycle is composed of four segments which are described as follows:

Chassis Transient Cycle

Segment	Time, sec
New York Non-Freeway (NYNF)	254
Los Angeles Non-Freeway (LANF)	267
Los Angeles Freeway (LAF)	285
New York Non-Freeway (NYNF)	254

One chassis transient cycle is a total of 1060 seconds, or approximately 18 minutes. Figure 3 is a graphical representation of the chassis transient driving cycle. Although

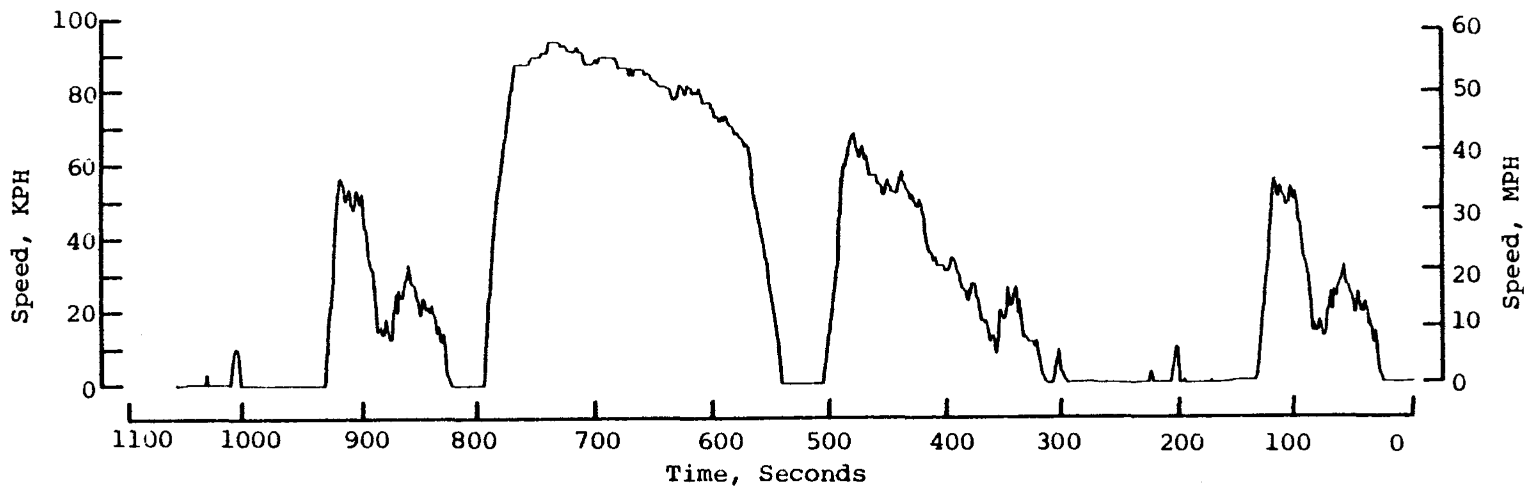


Figure 3. Heavy-duty chassis driving cycle

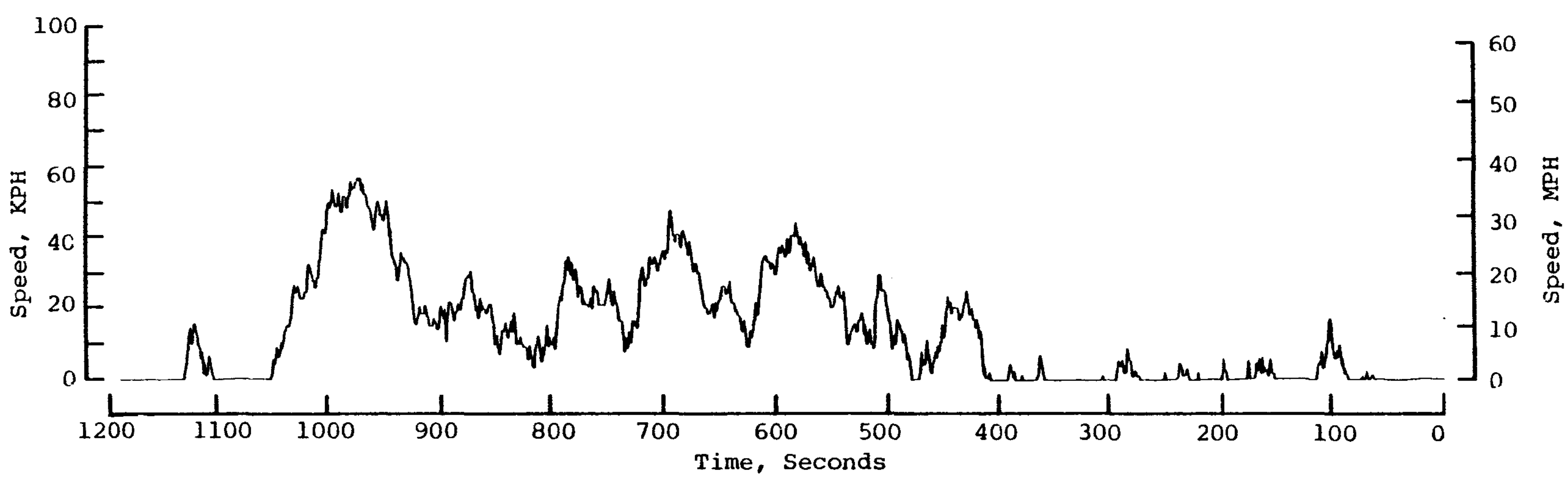


Figure 4. Heavy-duty chassis New York Bus Cycle

engine and chassis transient cycles are quite similar in most respects, differences in cycle lengths exist because of inherent differences in the chassis and engine test procedures.

Another driving cycle used in testing of buses in Task 3 was the New York Bus cycle. The driving cycle is shown in Figure 4. This experimental driving cycle was developed from a CAPE-21 study of several buses during in-service operation. Of the 1191 seconds duration of the cycle, 394 seconds are idle. The distance covered by the test is 2.90 miles and the maximum speed called for by the cycle is 36 mph.

UNREGULATED EMISSIONS

Vehicle exhaust was analyzed for a number of unregulated emissions: aldehydes and ketones, phenols, odor, organic extractables, and various elements. Organic soluble samples were analyzed to determine the concentration of nitropyrenes and to determine mutagenic activity of the soluble material using Ames bioassay.

Phenols

Vehicle exhaust was sampled for phenols by bubbling the exhaust through glass impingers containing a chilled aqueous solution of 1N potassium hydroxide. Dilute exhaust was passed through two impingers in series at approximately 0.8 ft^3/min. The sample was acidified, extracted with ether, and concentrated to 2 milliliters. The phenol sample was analyzed using a gas chromatograph (GC) equipped with a flame ionization detector. This procedure permits the analysis for phenol; salicyladehyde; m-cresol/p-cresol; p-ethylphenol/2-isopropylphenol/2,3-xylenol/3,5-xylenol/2,4,6-trimethylphenol; 2,3,5-trimethylphenol; and 2,3,5,6-tetramethylphenol. A detailed procedure is described in the Interim Report to EPA, Analytical Procedures for Characterizing Unregulated Emissions from Vehicles Using Middle-Distillate Fuels.(5)

Aldehydes and Ketones

Two variations of the 2,4-dinitrophenyl hydrazine (DNPH) method were used in the analysis of aldehydes and ketones in this program. The first method was applied to samples from Vehicles 3-1, through 3-7. It involved sampling dilute vehicle exhaust at 4 lit/min through an aqueous 2N HCL scrubber solution of 2,4-dinitrophenylhydrazine, . This converts aldehydes and ketones in exhaust to their hydrazone derivatives which are then filtered and extracted with pentane. The derivatives are subsequently dissolved in 2 milliliters of methanol and analyzed using an HPLC consisting of a Perkin Elmer Series 2/2 Pump and a Perkin Elmer LC-75 variable wavelength UV detector (set at 365 nm). The HPLC was gradient programmed from 70 percent methanol in water to 100 percent methanol (1.1 milliliters/min) at 0.3 percent methanol/min. The analytical column was a 25 cm x 4.6 mm Zorbax ODS column. The compounds measured by this procedure are formaldehyde, acetaldehyde, acrolein, propionaldehyde, acetone, crotonaldehyde, isobutyraldehyde, methylethylketone, benzaldehyde, and hexanaldehyde.

The second aldehyde and ketone procedure, an improved 2,4-DNPH Technique(6), was used to analyze samples from Vehicles 3-8 through 3-24. This method required less workup than the original procedure since the filtration, extraction, and transfer steps were eliminated. An aliquot of each sample was directly analyzed on the HPLC.

Initially, the minimum detection values (MDVS) using the new method were not as sensitive as the MDVS of the previous method. As shown in Table 9, the new method, as used to analyze samples from Vehicles 3-8 through 3-13, was significantly less sensitive than the original aldehyde and ketone procedure. Sensitivity was improved by installing a more sensitive fixed wavelength detector (Perkin Elmer LC-15B, set at 360nm). The improved sensitivity is reflected in the MDVS for samples from Vehicles 3-14 through 3-24, also shown in Table 9.

TABLE 9. MINIMUM DETECTION VALUES FOR ALDEHYDE AND KETONE SAMPLES COLLECTED DURING 1 COLD FTP AND 3 HOT FTPs

	Emission Rate, mg/km		
	Vehicles 3-3 to 3-7[a]	Vehicles 3-8 to 3-13[b]	Vehicles 3-14 to 3-24[c]
Formaldehyde	1	10	0.5
Acetaldehyde	1	13	0.7
Acrolein	1	16	0.8
Propionaldehyde	1	17	0.9
Acetone	1	17	0.9
Crotonaldehyde	2	19	1.0
Isobutyraldehyde	2	19	1.0 }
Methylethylketone	2	19	}
Benzaldehyde	2	25	1.0
Hexanaldehyde	2	24	1.3

[a] Original aldehyde and ketone procedure, samples extracted with pentane
[b] Improved aldehyde and ketone procedure, direct sample analysis
[c] Improved aldehyde and ketone procedure, more sensitive detector

The improved 2,4-DNPH technique involved bubbling dilute exhaust through a solution of DNPH in acetonitrile containing 1 drop of 1N perchloric acid per 5 milliliters of absorbing solution. A portion of the sampling solution is then analyzed by a direct injection (no extraction) into the HPLC. The HPLC mobile phase consists of a 70:30 mix (V:V) acetonitrile and water (0.3 milliliters/min flow rate) with a gradient from 70 to 100 percent acetonitrile at 1 percent acetonitrile/min. This variation of the procedure measures the same aldehydes and ketones as the first method, with the exception that isobutyraldehyde and methylethylketone elute at the same retention time.

Diesel Odor Analysis System (DOAS)

Dilute vehicle exhaust was sampled for odorants using stainless steel traps packed with Chromosorb-102. Two traps were positioned in series for each sample taken. The flowrate of exhaust through the traps was set at approximately 2.8 lit/min. After sampling, the odorants on each trap were eluted with 2 milliliters of cyclohexane. A portion of each sample was analyzed on the Diesel Odor Analysis System (DOAS), a liquid chromatography system designed for the measurement of two classes of odorous compounds in diesel exhaust.[7,8,9] Oily-kerosene aromatics (LCA) and smoky-burnt oxygenates (LCO) were separated and analyzed with a UV detector at 254 nm.

Elements

Particulate samples collected on 47mm Pallflex filters were analyzed for several elements at EPA-RTP using x-ray fluorescence.(10) The analyses were performed on a Siemens MRS-3 x-ray spectrometer.

Solvent Extraction of Particulate Filters

Particulate was sampled from dilute vehicle exhaust on three 20 X 20 inch Pallflex filters during each test cycle. Generally, one cold-start filter and three hot-start filters were extracted. The filters were individually soxhlet extracted with 400 milliliters of methylene chloride for 8 hours at 4 cycles/hour. The sample volume was reduced under vacuum to approximately 20-30 milliliters using a rotary evaporator. Each extract was then quantitatively transferred to a 50 milliliter volumetric flask and the volume adjusted to the mark. Half of the cold-start extract and half of the hot-start extract were pipetted out and individually dried and weighed. Percent extractables were calculated based on the fraction of cold- and hot-start extract taken to dryness. Cold-start and hot-start extracts were combined in the proportions 1/7 cold-start to 6/7 hot-start for the Ames and nitropyrene analyses. Ames bioassay required a minimum of 43 mg of extract and nitropyrene analysis needed approximately 10 mg. For some vehicles, additional filters had to be generated and extracted to obtain the desired extract weight.

Nitropyrenes

The determination of nitropyrenes (1-nitropyrene, 1,3-dinitropyrene, 1,6-dinitropyrene, and 1,8-dinitropyrene) was accomplished using a method developed by the U.S. Environmental Protection Agency.(11) Nitropyrenes were determined using Soxhlet extracted samples. The Soxhlet extracted sample was redissolved in a 50:50 mixture of methylene chloride/methanol. The volume of solvent used is dependent on an estimate of the nitropyrene levels in the sample. Nitropyrenes were analyzed using a reduction catalyst which converts nitropyrenes to aminopyrenes and a High Performance Liquid Chromatograph coupled to a fluorescence detector. A schematic of the analytical system is shown in Figure 5. Two reduction catalysts are used in the system. The first catalyst removes oxidative compounds from the solvent and the second catalyst converts nitropyrenes to the highly fluorescent aminopyrenes. Two Zorbax ODS analytical columns are used in the system. The first column separates any aminopyrenes present in the extract from the nitropyrenes before they enter the reduction catalyst. The second ODS column further separates the reduced nitropyrenes (aminopyrenes at this point) from other interfering compounds in the extract. The excitation and emission wavelength settings for the fluorescence detector are 360 and 430 nm , respectively, when analyzing for 1-nitropyrene and 370 and 433 nm, respectively, when analyzing for dinitropyrenes. Several of the operating parameters for the system are as follows:

Mobile Phase:	77% Methanol/23% water (V:V)
Mobile Phase Flow Rate:	1.1 milliliters per minute
Sample Size:	25 microliters
Catalyst Columns:	3 inch X 4.6 mm column packed with ground-up (70 mesh) 3-way catalyst from a U.S. automobile

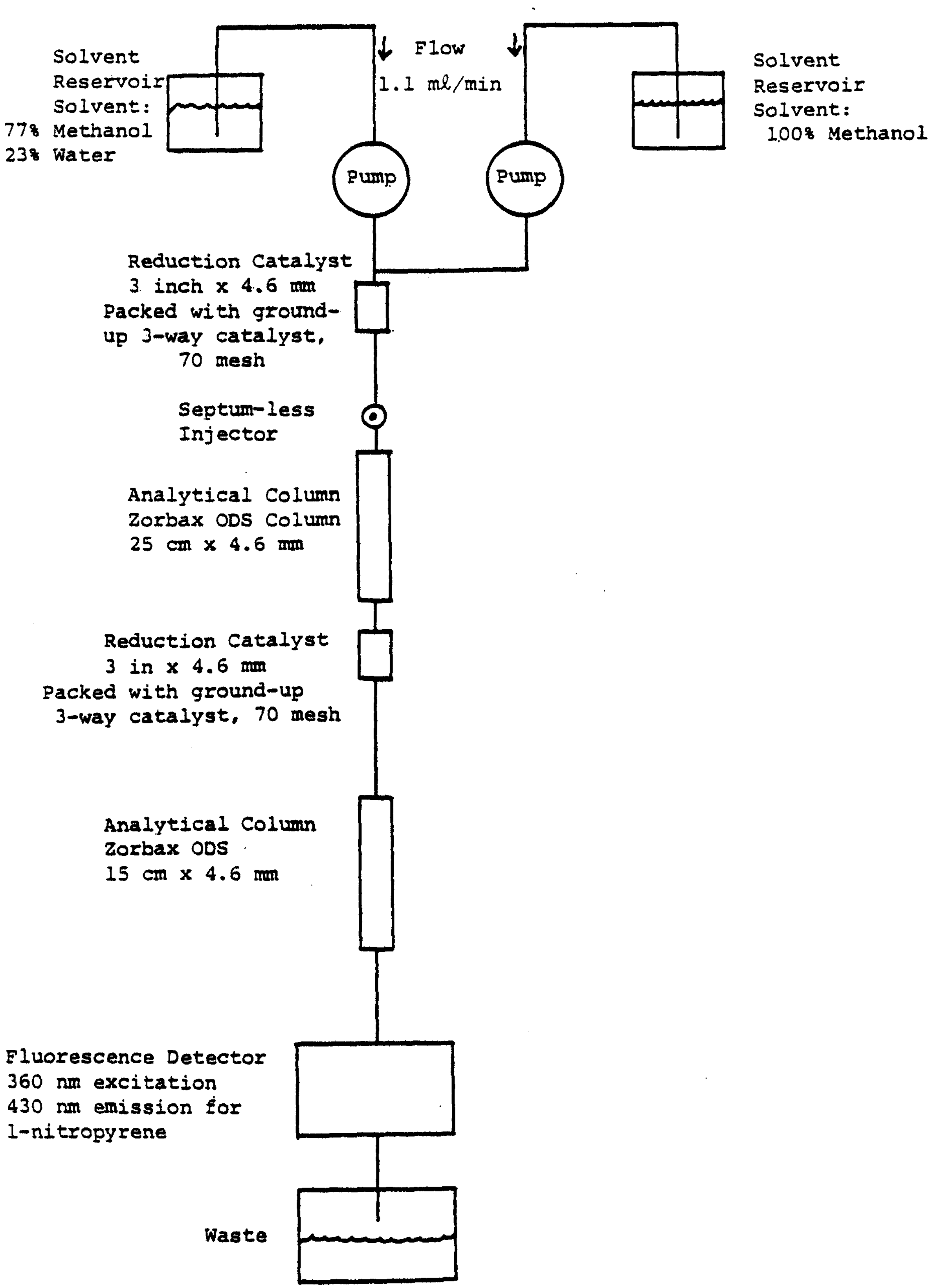


Figure 5. Schematic of nitropyrene analysis system

Catalyst Temperatures: 80°C
Analytical Columns: 25 cm X 4.6 mm Zorbax ODS

1-nitropyrene is eluted through the analytical system in approximately 38 minutes. Dinitropyrenes elute with retention times ranging from approximately 29 to 40 minutes. Nitropyrenes are quantified against standards in methylene chloride/methanol solutions. The 1-nitropyrene (99.9% purity) and a mixture of three dinitropyrenes were purchased from Midwest Research Institute and used for preparation of the standard solutions.

Ames Bioassay

Organic extractables were analyzed for mutagenic activity by the S. typhimurium mutagenicity test (Ames test)(12), in tester strains TA1538, TA98, and TA100. The samples were analyzed in triplicate for mutagenic activity in the presence and absence of the S9 external metabolic activation system, Aroclor-induced rat liver homogenate. Due to the importance attached to the potent mutagenic activity seen with nitro-containing polycyclic aromatic hydrocarbons (PAHs), particularly those identified in extracts of diesel exhaust, 1-nitropyrene was also included with the standard diagnostic mutagens as recommended by Maron and Ames.(13)

QUALITY ASSURANCE

The quality assurance requirements of this program were divided into three areas, preparation of a quality assurance project plan, participation in performance audits, and maintenance of records and documentation of calibration, raw data, and computer printouts. The quality assurance project plan was prepared according to the guidelines established in the project proposal. The plan described and outlined calibration techniques and frequency, accuracy and precision of data, measurement and testing procedures, and internal quality control checks. To conform to the requirement of performance audits, personnel from the Department of Quality Assurance and Administration at SwRI made periodic on-site qualitative system audits.

The following records have been maintained:

1. Calibration and maintenance records on the dynamometer, CVS, gas analyzers, gas chromatographs, high pressure liquid chromatographs, and filter weighing chamber and microbalance.

2. Vehicle specification sheets including basic operating check.

3. Raw data sheets for all tests and cycles in which regulated and unregulated measurements were made.

4. Laboratory notebooks containing filter weights and percent extracted solubles calculations.

5. Data encoding sheets, computer printouts and data reduction program of the CDC Cyber 172 computer.

6. A file of HP-67 computer programs used in the calibration of laboratory equipment and analyzers, and for the calculation of unregulated emissions.

In addition to the quality assurance requirements, good engineering practices were applied and Federal Register guidelines were followed throughout the program to ensure quality data.

A problem occurred with the testing of Vehicle 3-23 which was incorrectly operated at 80 percent of the desired horsepower. The wrong frontal area was used to calculate the air resistance term of the horsepower. This type of problem is not normally covered by a quality assurance plan. The data from the tests performed on Vehicle 3-23 were compared to data from previously tested vehicles and no unusual trends were observed. The error was discovered when dynamometer pararmeters were being compared. An additional vehicle was tested at the correct horsepower to provide the desired data.

SECTION 5

RESULTS

The scope of this program included the measurement of regulated and unregulated emissions from trucks and buses under transient operation. Regulated emissions which were measured included HC, CO, CO_2, and NO_x. The measurement of unregulated emissions included particulates, aldehydes, ketones, phenols, nitropyrenes, various elements, and DOAS odor. Also, Ames bioassay analyses were conducted on organic extracts from particulate filters. Emissions data were compared and trends noted, however, specific correlations of emissions were beyond the scope of this project. Task 2 involved the measurement of regulated emissions and particulate in both chassis and engine evaluations. Task 3 involved the measurement of regulated and unregulated emissions in chassis evaluations, the effect of vehicle inertia on emissions, and limited engine evaluations. The emissions results for all tests conducted are given in Appendix B for the Task 2 evaluations and in Appendix C for Task 3 evaluations. When composite emissions are given, the values were calculated by weighting cold-start and hot-start emissions by 1/7 and 6/7, respectively.

ENGINE VS CHASSIS EMISSIONS SUMMARY

Engines from six of the test vehicles (Vehicles 2-1, 2-2, 2-3, 2-4, 3-23, and 3-24) were removed and tested over the engine transient cycle and the vehicles were tested over the chassis transient cycle. The engine transient procedure produces emission results expressed on a brake specific basis, i.e., g/hp-hr. The chassis transient cycle produces emission results expressed in g/km. In 1978, EPA had determined that the average equivalent distance traveled during an engine transient test was 10.3 km. This distance was used for engine transient results converted to g/km. Another method of comparison is on a fuel specific basis, i.e., g/kg fuel. This method is also used in comparing engine and chassis transient emission results.

Emission results from six vehicles are listed by cold-start, hot-start and composite in Appendix D and are summarized in Appendix E. HC, CO, NO_x and particulate emissions (in g/km) from chassis and engine tests are compared in Figures 6, 7, 8, and 9, respectively, and summarized in Table 10 in g/km. HC chassis emissions generally exceeded engine emissions by 10 to 30 percent with the exception of Vehicle 2-1, in which chassis HC was lower than engine HC by 16 percent. Vehicle 3-23 emitted the highest level of chassis and engine HC while Vehicle 2-4 produced the lowest levels. Vehicle 2-1, had relatively high chassis CO emissions, 21 g/km compared to the other vehicles, 2 to 6 g/km. NO_x emissions from Vehicles 2-2, 2-3, 2-4, and 3-24 chassis and engine tests agreed within 11 percent. However, NO_x produced by Vehicle 2-1 during chassis tests exceeded engine NO_x by 65 percent while NO_x from Vehicle 3-23 chassis tests were 38 percent lower than engine NO_x. Vehicle 3-24 produced the highest NO_x levels of the six vehicles. Particulate emissions from chassis tests were generally higher than particulate produced during engine testing (by 18 to 28 percent). Vehicle

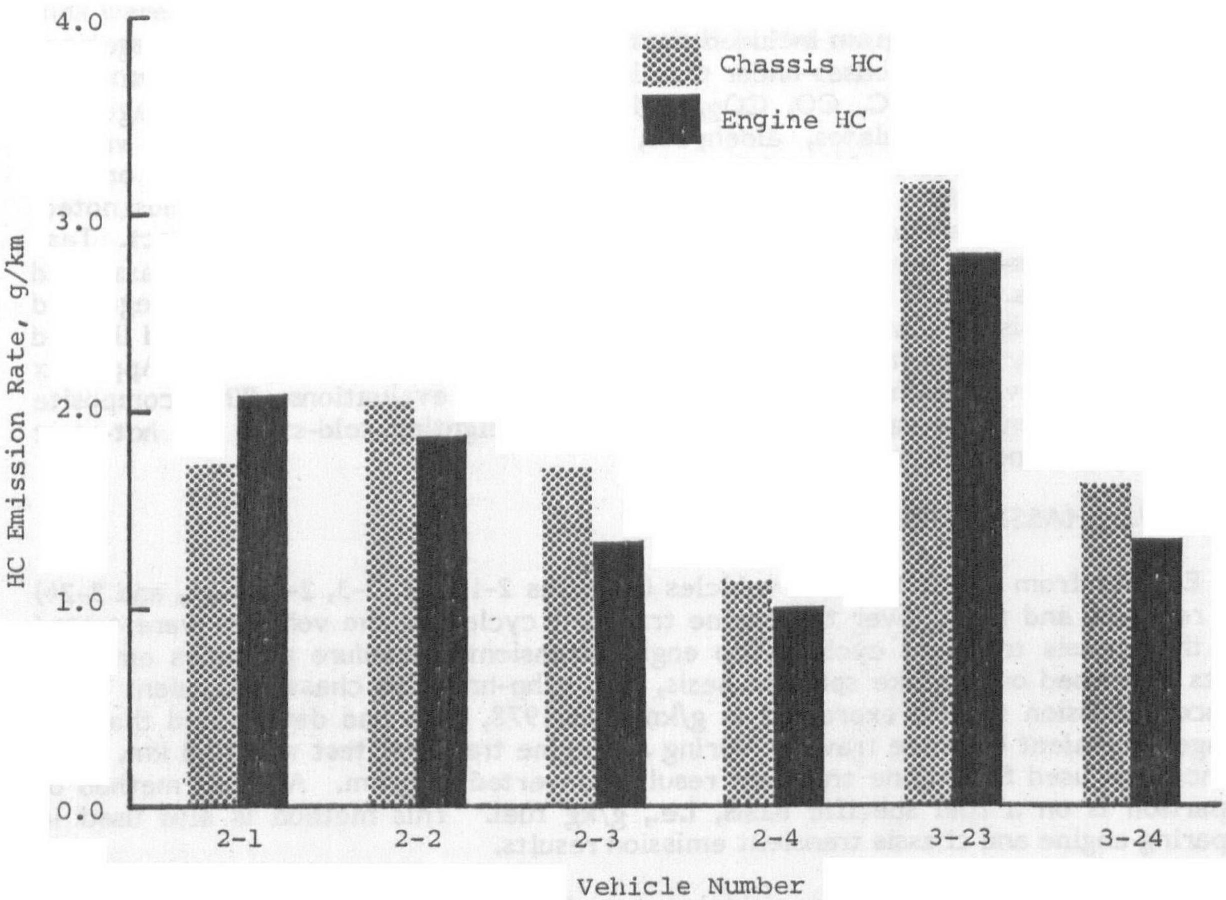


Figure 6. Comparison of HC emissions from chassis and engine tests, g/km

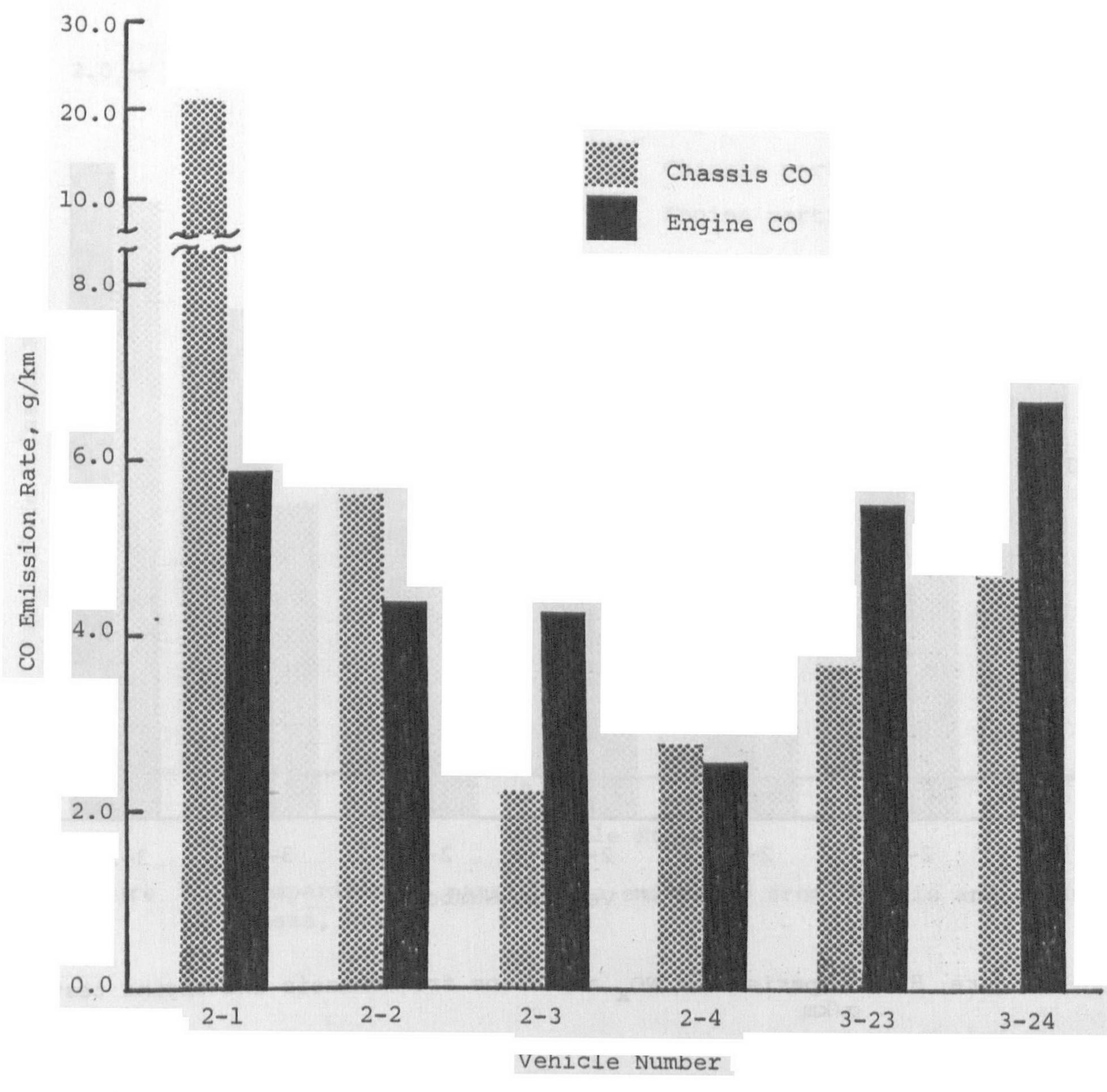


Figure 7. Comparison of CO emissions from chassis and engine tests, g/km

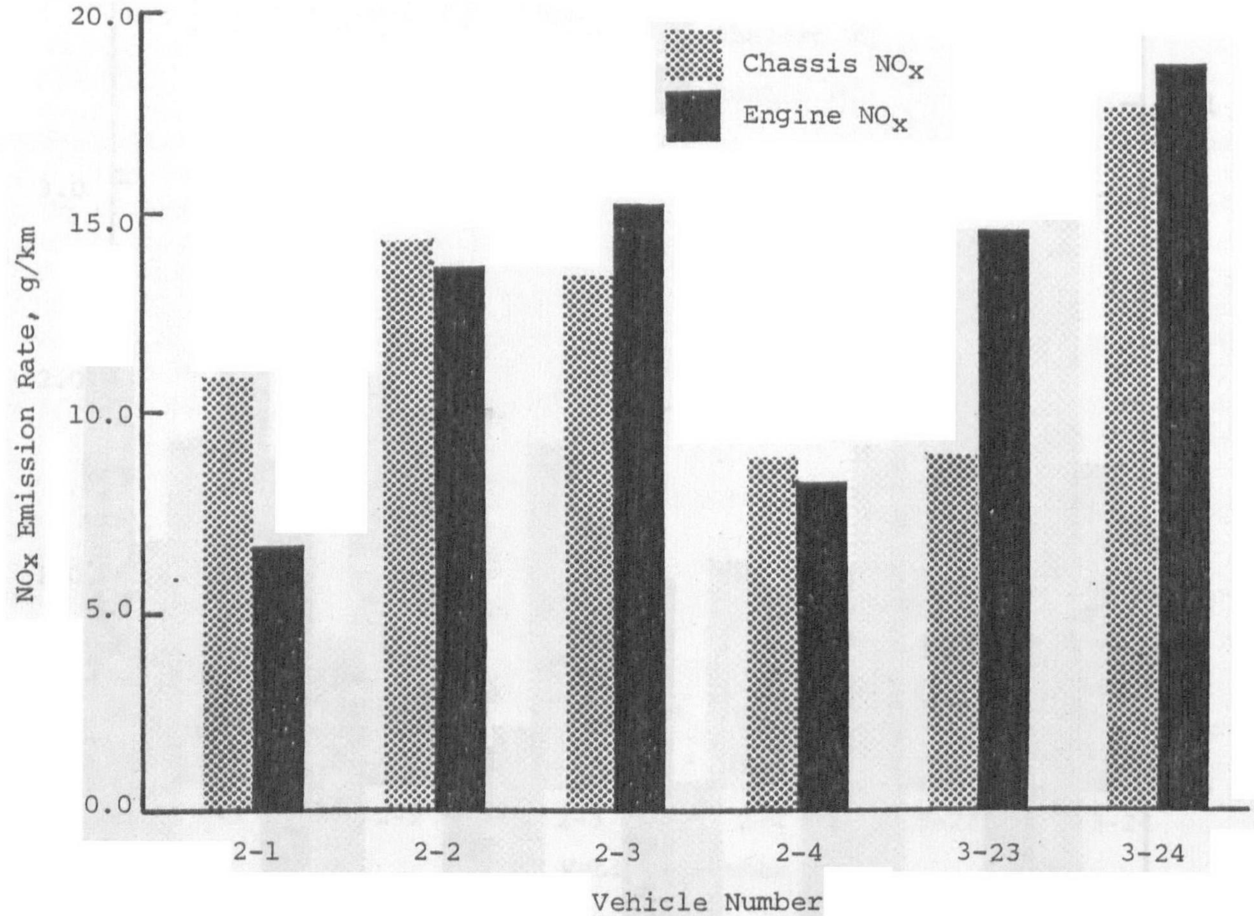


Figure 8. Comparison of NO_x emissions from chassis and engine tests, g/km

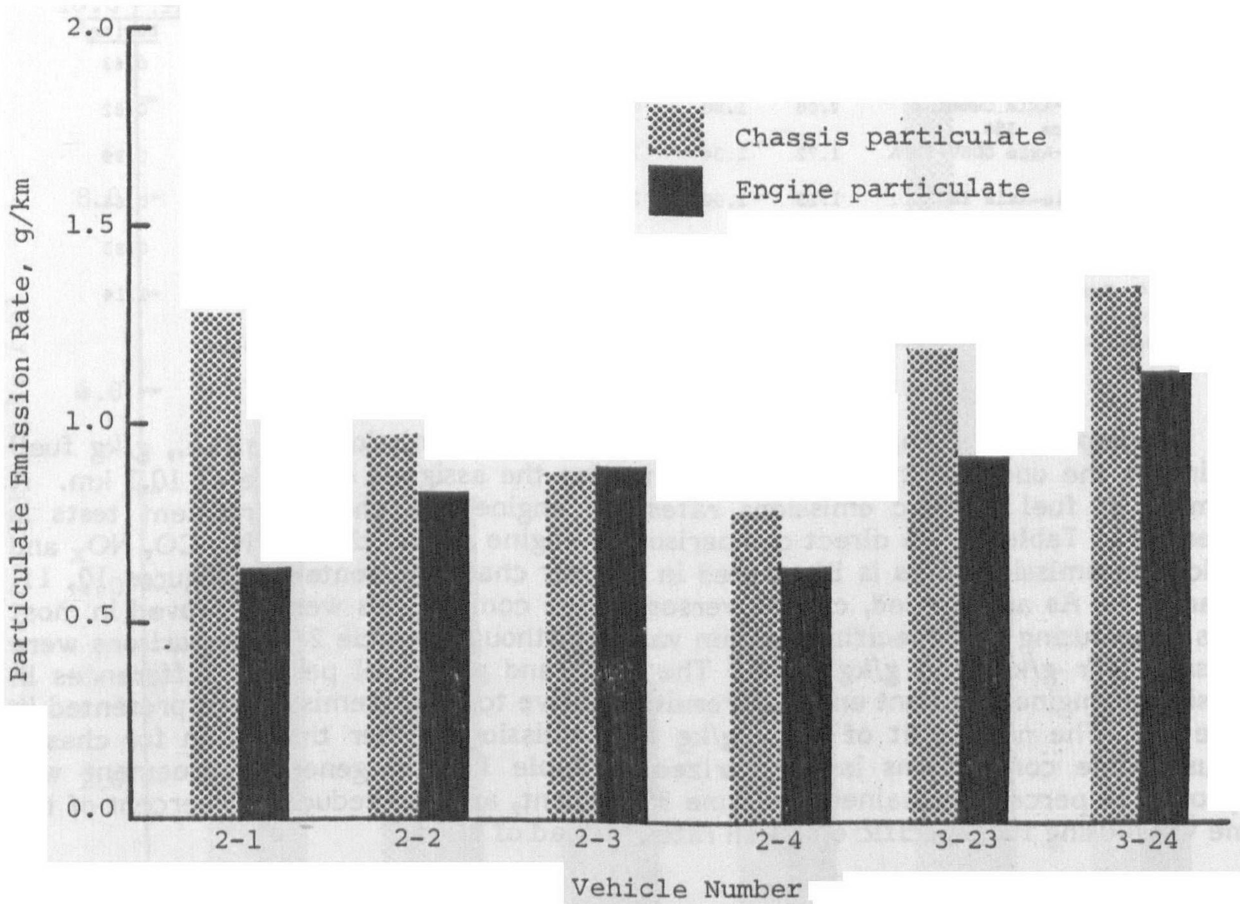


Figure 9. Comparison of particulate emissions from chassis and engine tests, g/km

2-3 produced nearly equivalent amounts of particulate in chassis and engine tests. Particulate emissions from chassis tests of Vehicle 2-1 were double the amount of particulate emissions from engine tests.

TABLE 10. COMPARISON OF EMISSIONS FROM CHASSIS AND ENGINE TESTS FROM SEVERAL VEHICLES

Vehicle Number	Vehicle Description	Composite Emission Rate, g/km HC Chassis	HC Engine[a]	CO Chassis	CO Engine[a]	NO_x Chassis	NO_x Engine[a]	Part. Chassis	Part. Engine[a]
2-1	Bus DD6V-71	1.74	2.08	21.4	5.92	10.8	6.56	1.28	0.63
2-2	Dual-Axle Cummins Form. 350	2.06	1.88	5.56	4.39	14.3	13.7	0.97	0.82
2-3	Dual-Axle DD8V-92TA	1.72	1.34	2.24	4.33	13.4	15.1	0.87	0.89
2-4	Single-Axle IHC DT-466	1.15	1.00	2.82	2.62	8.91	8.31	0.78	0.64
3-23	Single-Axle Cummins NTC-300	3.16	2.80	3.70	5.55	8.99	14.6	1.19	0.93
3-24	Dual-Axle DD8V-92TA	1.62	1.36	4.67	6.66	17.6	18.7	1.35	1.14

[a]Engine transient emission rate based on an engine equivalent distance of 10.3 km.

A comparison of engine and chassis fuel specific emission rates (i.e., g/kg fuel) eliminates the uncertainty associated with using the assigned distance of 10.3 km. A summary of fuel specific emissions rates for engine and chassis transient tests is presented in Table 11. A direct comparison of engine versus chassis HC, CO, NO_x and particulate emission rates is illustrated in the bar charts presented as Figures 10, 11, 12, and 13. As anticipated, chassis versus engine comparisons were improved in most cases when using fuel specific emission values (although Vehicle 2-3 comparisons were the same for g/km and g/kg fuel). The g/km and g/kg fuel percent differences in chassis and engine transient emission results relative to engine emissions is presented in Table 12. The net result of using g/kg fuel emissions rather than g/km for chassis versus engine comparisons is summarized in Table 13. In general, agreement was improved 54 percent, remained the same 33 percent, and was reduced 13 percent of the time when using fuel specific emission rates instead of g/km.

TABLE 11. COMPARISON OF EMISSIONS FROM CHASSIS AND ENGINE TRANSIENT TESTS FROM SEVERAL VEHICLES (g/kg fuel)

Vehicle Number	Composite Emission Rate, g/kg fuel HC Chassis	HC Engine	CO Chassis	CO Engine	NO_x Chassis	NO_x Engine	Particulate Chassis	Particulate Engine
2-1	4.23	7.25	51.9	20.5	26.4	22.8	3.10	2.21
2-2	4.69	4.83	12.7	11.3	32.7	34.6	2.21	2.12
2-3	3.81	2.97	4.97	9.50	29.8	33.2	1.93	1.94
2-4	3.69	3.63	8.89	9.47	28.1	30.1	2.50	2.30
3-23	9.60	7.26	11.2	14.4	27.2	37.9	3.59	2.42
3-24	3.18	2.71	9.17	13.3	34.4	37.2	2.64	2.28

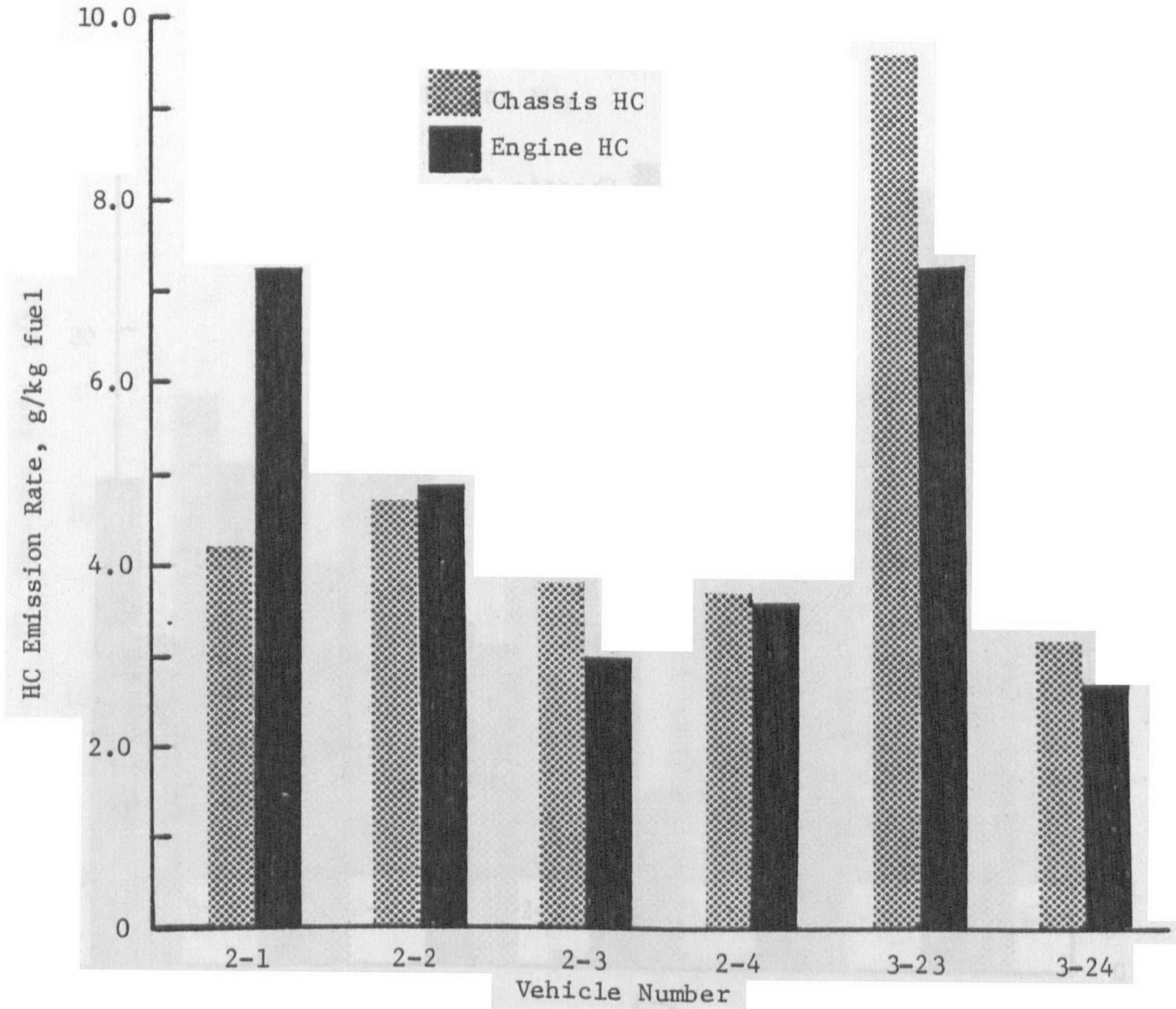


Figure 10. Comparison of HC emissions from chassis and engine tests, g/kg fuel

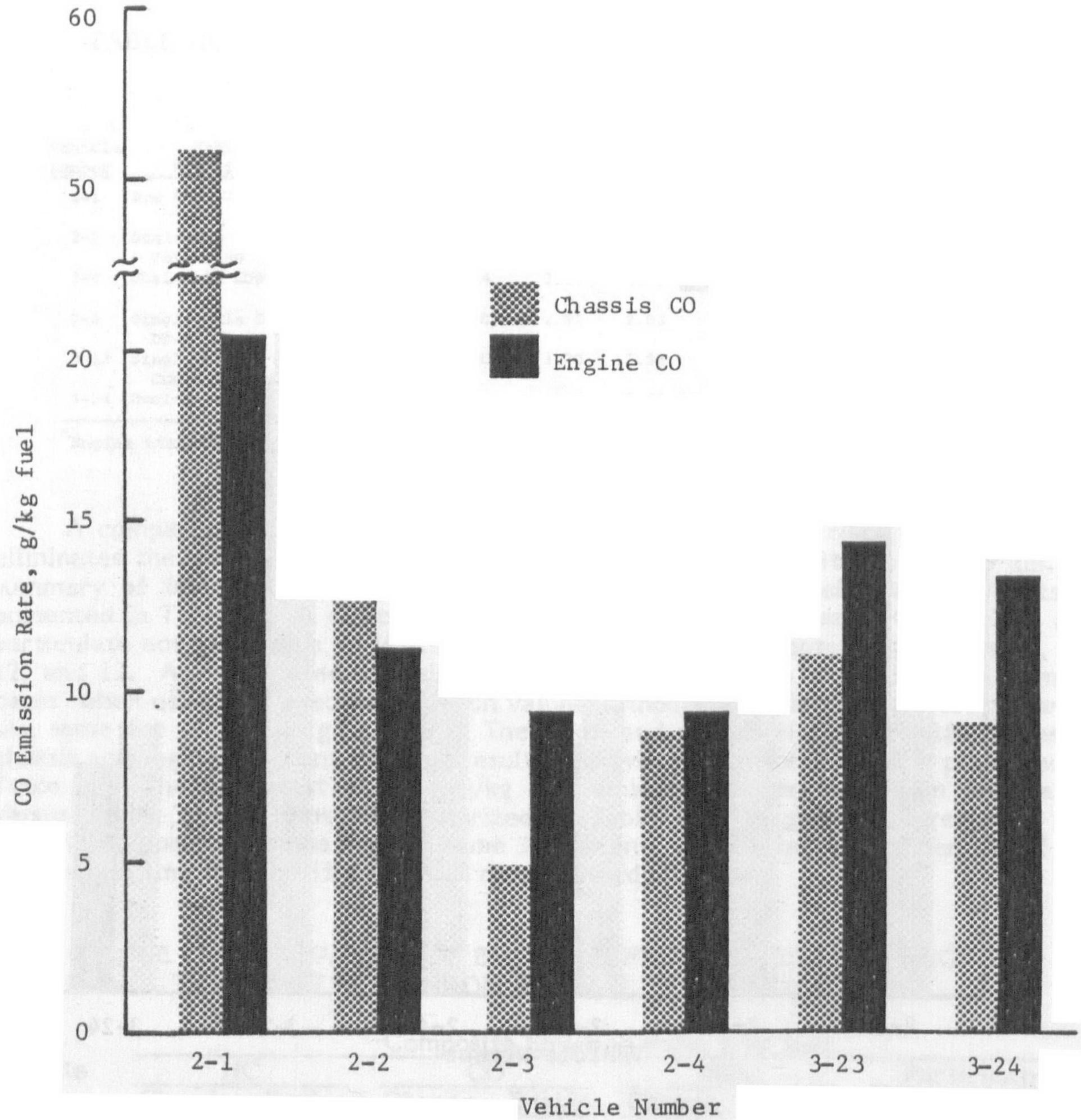


Figure 11. Comparison of CO emissions from chassis and engine tests, g/kg fuel

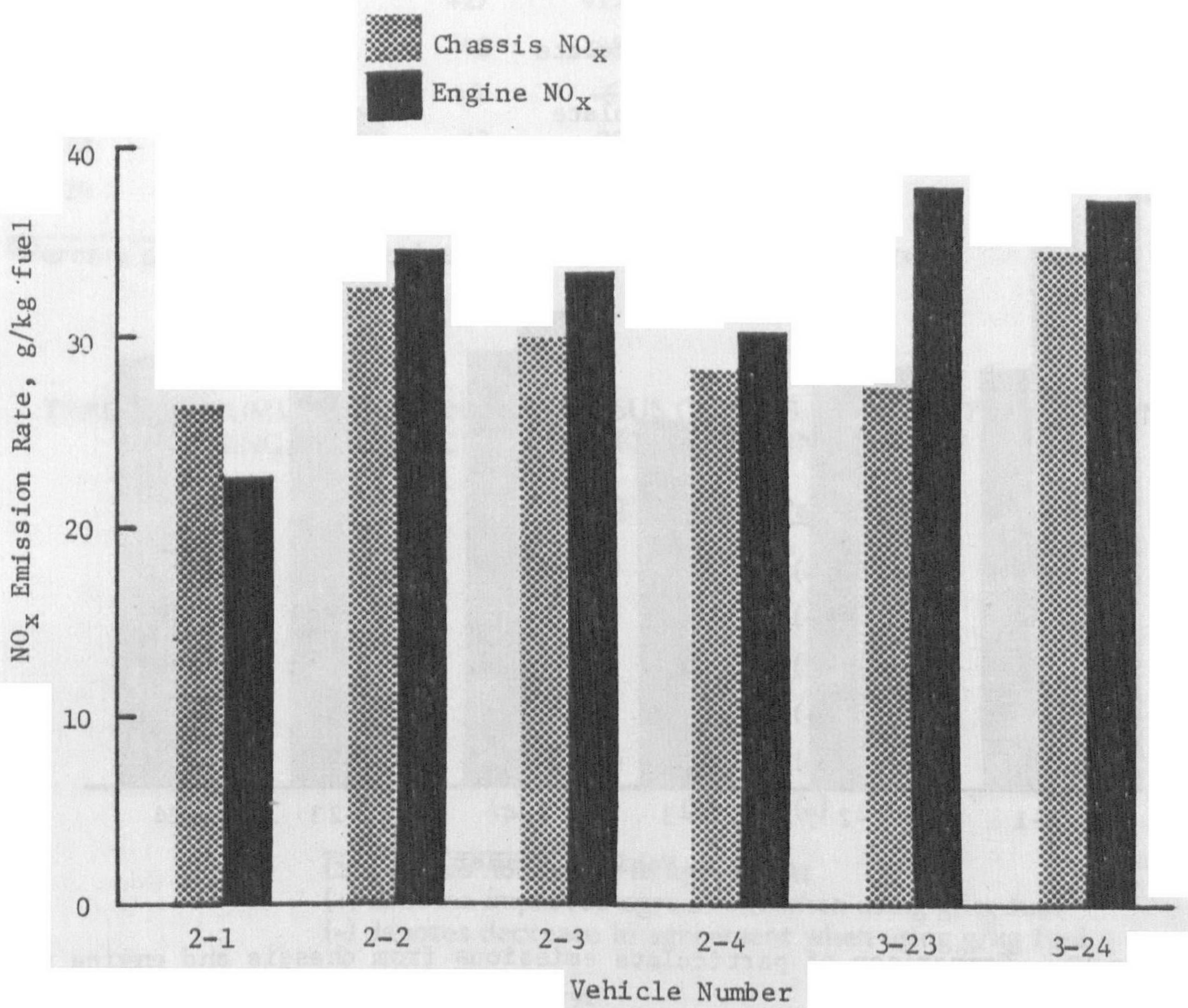


Figure 12. Comparison of NO_x emissions from chassis and engine tests, g/kg fuel

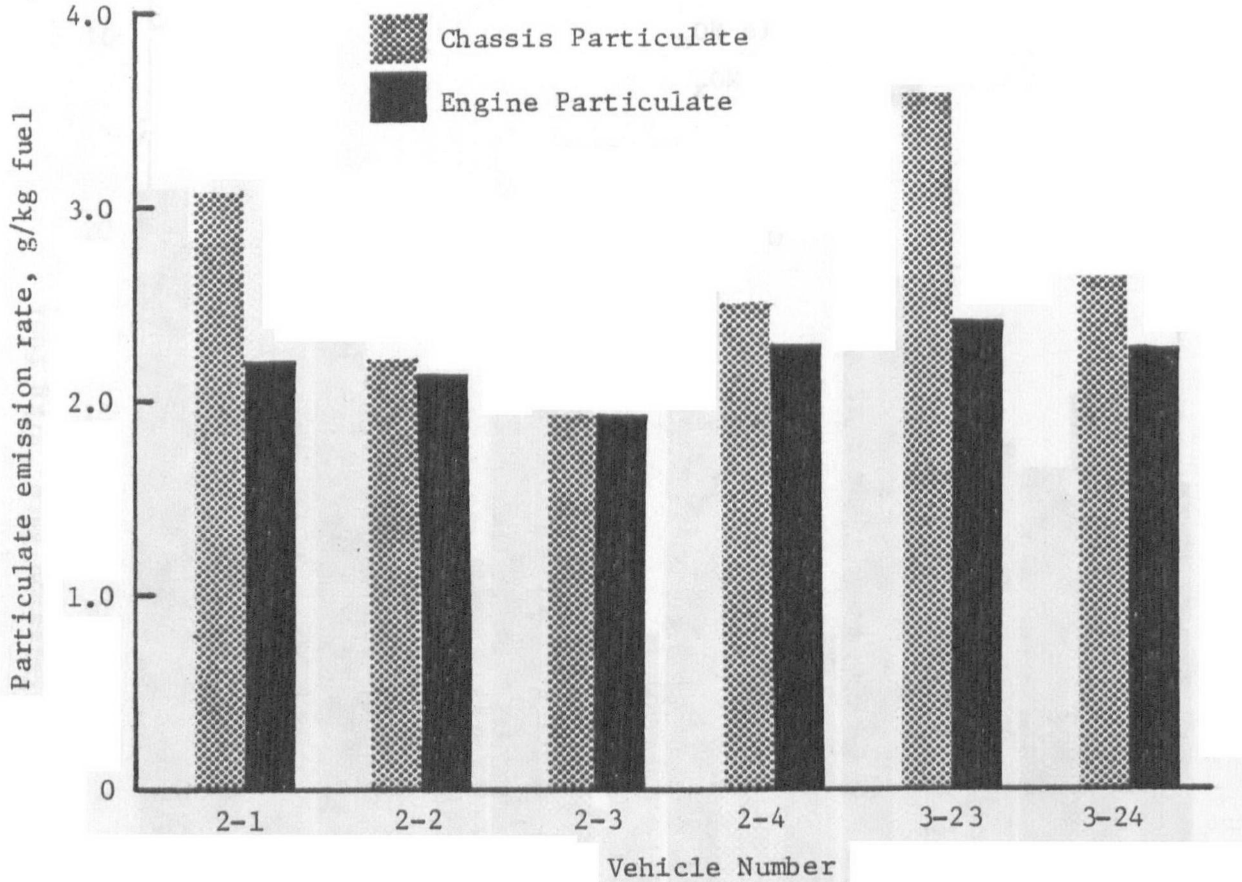


Figure 13. Comparison of particulate emissions from chassis and engine tests, g/kg fuel

TABLE 12. COMPARISON OF ENGINE AND CHASSIS EMISSION RATE DIFFERENCES BASED ON g/km AND g/kg fuel[a]

Vehicle Number	Percent Difference Between Chassis and Transient Emission Rates							
	HC		CO		NO_x		Particulate	
	g/km	g/kg fuel	g/km	g/kg fuel	g/km	g/kg fuel	g/km	g/kg fuel
2-1	-16	-42	+261	+153	+65	+16	+103	+40
2-2	+10	-3	+27	+12	+4	-5	+18	+4
2-3	+28	+28	-48	-48	-11	-10	-2	-1
2-4	+15	+2	+8	-6	+7	-7	+22	+9
3-23	+13	+32	-33	-22	-38	-28	+28	+49
3-24	+19	+17	-30	-31	-6	-8	+18	+16

[a]Percent differences were calculated relative to engine emissions

TABLE 13. SUMMARY OF ENGINE VERSUS CHASSIS TRANSIENT AGREEMENTS USING FUEL SPECIFIC EMISSION RATES INSTEAD OF g/km

Vehicle	HC	CO	NO_x	Part.
2-1	(-)	(+)	(+)	(+)
2-2	(+)	(+)	(±)	(+)
2-3	(±)	(±)	(±)	(±)
2-4	(+)	(±)	(±)	(+)
3-23	(-)	(+)	(+)	(-)
3-24	(+)	(+)	(±)	(+)

(±) denotes no change in agreement
(+) denotes improved agreement when using g/kg fuel
(-) denotes decrease in agreement when using g/kg fuel

Recap of Summary:
(+) = 13/24 or 54 percent
(±) = 8/24 or 33 percent
(-) = 3/24 or 12 percent

The limited amount of chassis and engine data obtained in this project provides an opportunity to speculate on the reasons for agreement and disagreement. The engine transient procedure is basically well defined and accordingly does not address the end application of the engine. Although this is the appropriate approach for certification, it does not account for the end-use of the engine. The engine transient cycle basically exercises the engine over a speed-load map based on the capability of the engine. In the case of the chassis transient cycle, many variables exist and a number of assumptions must be made. For example, in setting horsepower and inertia during chassis testing, assumptions about the size of trailer being pulled (i.e., frontal area) and inertia weight had to be made. In some cases, it is possible to get an engine in either a single-axle or a dual-axle truck, such as a Cummins 300. In the case of the single-axle truck, the engine is only required to deliver a portion of the power it is capable of producing; whereas, in a dual-axle vehicle, the engine is required to work considerably harder.

In addition to the assumptions associated with determination of load and inertia and engine-vehicle match, other parameters must be considered. These include tires, transmission, etc. The effect of transmission is best illustrated by the city bus powered by the DD 6V-71. The engine transient emission results of the DD 6V-71 were relatively close to the emissions results from other heavy-duty engines tested; however, when the engine was reinstalled in the bus and tested over the chassis transient cycle, CO, NO_x and particulate emissions rates were significantly higher than the engine transient emissions. The lack of engine versus chassis emission agreement with the DD 6V-71 is suspected to be due to the automatic transmission in the bus. None of the other vehicles involved in engine versus chassis comparisons were equipped with automatic transmissions.

EFFECT OF INERTIA

Additional tests were performed over a range of inertia settings for two Vehicles, 3-23 and 3-24. These tests were performed to determine if a different inertia setting could provide a better correlation between engine and chassis emission tests. The emissions comparisons in the previous section involved testing with inertia settings of 70 percent of gross vehicle weight (GVW).

Chassis tests were performed on Vehicle 3-23 at 61%, 70%, 80%, and 93% of GVW. This vehicle was operated at a horsepower lower than usual due to a discrepancy in determining the frontal area of the vehicle. The dimensions of the front of the truck were used to calculate the air resistance term of road load horsepower instead of using the dimensions of a standard van semi-trailer. The resulting road load horsepower that was used was 84 hp at 50 mph instead of 104 hp at 50 mph, 19% low. At 40 mph, the road load was 53.5 hp versus normally used 64 hp, or 16% low. At 30 mph, road load was 32 hp versus normally used 36.5 hp or 12% low. At 20 mph, the road load was 7% low (17.6 hp vs 18.9) and at 10 mph, the road load was 7.6 hp vs 7.7 hp, or 1% low. Table 14 contains a summary of HC, CO, CO_2, NO_x, and particulate emissions and fuel economy from the five single-axle vehicles tested in this program. The CO, CO_2, NO_x, and particulate emission rates and fuel economy from Vehicle 3-23 fall within the range of values for Vehicles 2-4, 3-1, 3-2, and 3-3. The higher HC cannot be attributed to the road load difference.

Chassis tests were also performed on Vehicle 3-24 at four inertia settings, 55% 70%, 86%, and 97% of GVW. Tests were conducted at standard and reduced horsepower. The reduced horsepower dynamometer setting (80 percent of standard horsepower) was the dynamometer horsepower at which Vehicle 3-23 was incorrectly operated. Vehicle 3-24 was tested at both horsepower settings to determine if emissions would vary with dynamometer horsepower. Tests conducted on Vehicle 3-24 at reduced horsepower produced between 4 and 12 percent less CO, CO_2, NO_x, and

TABLE 14. SUMMARY OF SINGLE-AXLE VEHICLE EMISSION RESULTS AND FUEL ECONOMY

Vehicle ID	Year	Mfg.	Model	HP @ 50 mph	Emission Rate, g/km HC	CO	CO_2	NO_x	Part.	Fuel Economy, ℓ/100 km
2-4	1979	IHC	DT-466B	104	1.15	2.82	998	8.91	0.78	37.5
3-1	1978	CUM	F-350	104	2.18	3.76	1171	8.00	1.16	44.1
3-2	1979	IHC	DT-466	104	1.07	2.66	1008	10.8	0.81	37.8
3-3	1977	CUM	F-290	104	2.14	5.83	1066	9.15	1.43	40.3
3-23	1981	CUM	NTC-300	84	3.17	3.70	1036	8.00	1.19	39.2

particulate than tests performed at standard horsepower. HC emissions did not vary significantly between standard and reduced horsepower settings. However, these results do not necessarily imply the same relationship between horsepower and emissions for the single-axle tractor, Vehicle 3-23.

The test plan for the chassis operation of Vehicle 3-24 is shown in Table 15. Only hot-starts were performed at reduced horsepower at 86%, 97%, and 55% of GVW. The vehicle was operated over both cold- and hot-starts at reduced horsepower at 70 percent of GVW. Emissions results from individual tests of Vehicles 3-23 and 3-24 in g/km and g/kg fuel are found in Appendix C. Vehicles 3-23 and 3-24 emissions in g/km are summarized in Tables 16 and 17, respectively, while fuel specific emission rates are summarized in Tables 18 and 19.

TABLE 15. VEHICLE 3-24 TEST PLAN

Test Day	Inertia Weight	Test Condition	Test Number	Test Cycle
1	70% of GVW	standard HP	32421 R-1	cold, hot
2		standard HP	32421 R-2	cold, hot 1, hot 2, hot 3
3		reduced HP[a]	32421 R-3	cold, hot
4		reduced HP	32421 R-4	cold, hot
5	86% of GVW	standard HP	32422 R-1	cold, hot
		reduced HP	32422 R-2	hot 1, hot 2
6		standard HP	32422 R-3	cold, hot
		reduced HP	32422 R-4	hot 1, hot 2
7	97% of GVW	standard HP	32423 R-1	cold, hot
		reduced HP	32423 R-2	hot 1, hot 2
8		standard HP	32423 R-3	cold, hot
		reduced HP	32423 R-4	hot 1, hot 2
9	55% of GVW	standard HP	32424 R-1	cold, hot
		reduced HP	32424 R-2	hot 1, hot 2
10		standard HP	32424 R-3	cold, hot
		reduced HP	32424 R-4	hot 1, hot 2

[a]Reduced horsepower was 80 percent of standard horsepower

TABLE 16. SUMMARY OF EMISSIONS IN G/KM FROM VEHICLE 3-23 OPERATED AT SEVERAL INERTIA SETTINGS OVER THE CHASSIS TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)[a]

	Emission Rate, g/km[f]														
Percent	Cold-Start					Hot-Start					Composite				
of GVW	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.
61%	3.32	4.39	1102	8.21	1.56	3.33	3.69	989	8.40	1.16	3.33	3.79	1006	8.37	1.22
70%	3.18	4.20	1154	9.04	1.46	3.16	3.61	1016	8.99	1.14	3.16	3.70	1036	8.99	1.19
80%	3.42	4.52	1178	9.49	1.60	3.56	4.08	1099	10.6	1.26	3.54	4.15	1110	10.4	1.31
93%	3.27	4.81	1240	10.6	1.57	3.18	4.10	1136	10.9	1.22	3.14	4.20	1152	10.8	1.26
Avg.	3.30	4.48	1168	9.34	1.55	3.31	3.87	1060	9.72	1.20	3.29	3.96	1076	9.64	1.25
S.D.[c]	0.10	0.26	57	1.00	0.06	0.18	0.26	69	1.22	0.06	0.19	0.25	67	1.15	0.05
C.V.[d]	3	6	5	11	4	6	7	7	13	5	6	6	6	12	4
										C.V.[e]	3	4	1	3	6

[a] Vehicle 3-23 was tested at a reduced horsepower, 80% of standard
[b] NO_x from bag measurement
[c] Standard deviation
[d] Coefficient of variation, %
[e] Coefficient of variation from identical repetitive testing in Task 2
[f] Average of two tests

TABLE 17. SUMMARY OF EMISSIONS IN G/KM FROM VEHICLE 3-24 OPERATED AT SEVERAL INERTIA SETTINGS AT STANDARD AND REDUCED HORSEPOWER OVER THE CHASSIS TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

		Emission Rate, g/km														
		Cold-Start					Hot-Start					Composite				
Percent of GVW	Horsepower[a]	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.
55%	Standard	1.59	3.31	1514	14.6	1.14	1.74	3.37	1400	14.4	1.14	1.71	3.36	1416	14.4	1.14
	Reduced	—	—	—	—	—[c]	1.66	3.17	1324	12.9	1.07	—	—	—	—	—[c]
70%	Standard	1.59	4.37	1686	17.0	1.29	1.63	4.72	1596	17.6	1.36	1.62	4.67	1609	17.6	1.35
	Reduced	1.71	4.12	1606	16.4	1.23	1.68	4.13	1523	16.4	1.14	1.68	4.13	1534	16.4	1.16
86%	Standard	1.72	5.16	1866	20.5	1.28	1.64	5.92	1760	19.6	1.26	1.65	5.81	1775	19.8	1.26
	Reduced	—	—	—	—	—[c]	1.63	5.45	1596	17.3	1.11	—	—	—	—	—[c]
97%	Standard	1.71	6.65	1932	21.8	1.50	1.65	7.78	1833	21.5	1.40	1.66	7.62	1847	21.5	1.41
	Reduced	—	—	—	—	—[c]	1.66	7.11	1706	19.5	1.27	—	—	—	—	—[c]

[a] Horsepower programmed into dynamometer, reduced = 80% of standard
[b] NO_x from bag measurement
[c] No cold-start at reduced horsepower

TABLE 18. SUMMARY OF EMISSIONS IN G/KG FUEL FROM VEHICLE 3-23 OPERATED AT SEVERAL INERTIA SETTINGS OVER THE CHASSIS TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)[a]

	Emission Rate, g/kg fuel														
Percent	Cold-Start					Hot-Start					Composite				
of GVW	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.
61%	9.42	12.4	3130	23.3	4.44	10.5	11.7	3128	26.6	3.68	10.4	11.8	3128	26.1	3.80
70%	8.65	11.4	3133	24.6	3.96	9.76	11.1	3130	27.7	3.53	9.60	11.2	3130	27.2	3.59
80%	9.10	12.0	3130	25.2	4.24	10.2	11.6	3129	30.7	3.60	10.0	11.7	3128	30.0	3.68
93%	8.26	12.2	3134	26.7	3.97	8.60	11.3	3134	30.1	3.36	8.55	11.4	3134	29.6	3.44
Avg.	8.86	12.0	3132	25.0	4.15	9.77	11.4	3130	28.8	3.54	9.64	11.5	3130	28.2	3.63
S.D.[c]	0.51	0.4	2	1.4	0.23	0.83	0.3	3	1.9	0.14	0.80	0.3	3	1.9	0.15
C.V.[d]	6	4	<0.5	6	6	9	2	<0.5	7	4	8	2	<0.5	7	4

[a]Vehicle 3-23 was tested at a reduced horsepower, 80% of standard
[b]NO_x from bag measurement
[c]Standard deviation
[d]Coefficient of variation, %
[e]Coefficient of variation from identical repetitive testing in Task 2

TABLE 19. SUMMARY OF EMISSIONS IN G/KG FUEL FROM VEHICLE 3-24 OPERATED AT SEVERAL INERTIA SETTINGS AT STANDARD AND REDUCED HORSEPOWER OVER THE CHASSIS TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

		Emission Rate, g/kg fuel														
		Cold-Start					Hot-Start					Composite				
Percent of GVW	Horsepower[a]	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.
55%	Standard	3.32	6.90	3158	30.4	2.38	3.91	7.60	3155	32.4	2.56	3.83	7.50	3156	32.1	2.53
	Reduced	—[c]					3.96	7.55	3155	30.8	2.54	—[c]				
70%	Standard	2.97	8.19	3157	31.9	2.41	3.21	9.33	3154	34.8	2.68	3.18	9.17	3155	34.4	2.64
	Reduced	3.37	8.09	3157	32.2	2.42	3.47	8.55	3154	33.9	2.36	3.46	8.48	3155	33.7	2.37
86%	Standard	2.91	8.74	3157	34.7	2.16	2.93	10.6	3154	35.2	2.25	2.93	10.4	3154	35.2	2.24
	Reduced	—[c]					3.25	10.8	3152	33.9	2.20	—[c]				
97%	Standard	2.79	10.9	3153	85.5	2.44	2.83	13.4	3150	36.9	2.40	2.82	13.0	3150	36.7	2.41
	Reduced	—[c]					3.05	13.1	3149	36.0	2.35	—[c]				

[a]Horsepower programmed into dynamometer, reduced = 80% of standard
[b]NO_x from bag measurement
[c]No cold-start at reduced horsepower

Composite chassis and engine transient emission results from Vehicles 3-23 and 3-24 are presented in Tables 20 (g/km) and 21 (g/kg fuel). Engine transient g/km values were calculated using the EPA assigned 10.3 km as the vehicle equivalent distance of the engine transient test. This value is an average distance that the average engine would travel in a typical heavy-duty application. The 10.3 km distance may or may not represent the actual equivalent distance for Vehicles 3-23 and 3-24. Fuel specific (g/kg fuel) emission rates may be more appropriate for making engine and chassis comparisons. This section describes the comparison of engine and chassis transient emissions for emission rates expressed in g/km (based on the 10.3 km engine equivalent distance) and g/kg fuel, a fuel specific comparison.

TABLE 20. COMPARISON OF ENGINE AND CHASSIS EMISSIONS FROM VEHICLES 3-23 AND 3-24 MEASURED AT SEVERAL INERTIA SETTINGS (g/km)

Vehicle		Engine Emissions, g/km[a]					Percent	Chassis Emissions, g/km				
Number	Vehicle Description	HC	CO	CO_2	NO_x[b]	Part.	of GVW	HC	CO	CO_2	NO_x[b]	Part.
3-23[c]	Single-axle 1981 Cummins NTC-300	2.80	5.55	1211	14.6	0.93	61%	3.33	3.79	1006	8.37	1.22
							70%	3.16	3.70	1036	8.99	1.19
							80%	3.54	4.15	1110	10.4	1.31
							93%	3.14	4.20	1152	10.8	1.26
3-24	Dual-axle 1980 DD8V-92TA	1.36	6.66	1583	18.7	1.14	55%	1.71	3.36	1416	14.4	1.14
							70%	1.62	4.67	1609	17.6	1.35
							86%	1.65	5.81	1775	19.8	1.26
							97%	1.66	7.62	1847	21.5	1.41

[a]Engine emission rates are based on a 10.3 km engine test cycle
[b]NO_x from bag measurement
[c]Vehicle 3-23 chassis emissions were measured at 80 percent of standard horsepower

TABLE 21. COMPARISON OF COMPOSITE FUEL SPECIFIC ENGINE AND CHASSIS EMISSIONS FROM VEHICLES 3-23 AND 3-24 MEASURED AT SEVERAL INERTIA SETTINGS(g/kg fuel)

Vehicle		Engine Emissions, g/kg fuel					Percent	Chassis Emissions, g/kg fuel				
Number	Vehicle Description	HC	CO	CO_2	NO_x[a]	Part.	of GVW	HC	CO	CO_2	NO_x[a]	Part.
3-23[b]	Single-axle 1981 Cummins NTC-300	7.26	14.4	3136	37.9	2.42	61%	10.4	11.8	3128	26.1	3.80
							70%	9.60	11.2	3130	27.2	3.59
							80%	10.0	11.7	3128	30.0	3.68
							93%	8.55	11.4	3134	29.6	3.44
3-24	Dual-axle 1980 DD8V-92TA	2.71	13.3	3153	37.2	2.28	55%	3.83	7.50	3156	32.1	2.53
							70%	3.18	9.17	3155	34.4	2.64
							86%	2.93	10.4	3154	35.2	2.24
							97%	2.82	13.0	3150	36.7	2.41

[a]NO_x from bag measurement
[b]Vehicle 3-23 chassis emissions were measured at 80 percent of standard horsepower

Comparison of g/km emission rates for engine and chassis transient tests are presented in Figures 14, 15, 16, 17, and 18. The chassis tests for Vehicle 3-23 were conducted at 61, 70, 80, and 93 percent of GVW. Vehicle 3-24 was tested at 55, 70, 86, and 97 percent of GVW. Figure 14 illustrates the relationship between HC g/km emissions from Vehicles 3-23 and 3-24 tested over the engine transient cycle and the chassis transient cycle using several inertia weights. Vehicle 3-23 chassis HC were about 20 percent higher than engine HC, while engine HC from Vehicle 3-24 was about 20 percent higher than chassis HC. Inertia had little effect on chassis emissions from either vehicle.

Figure 15 presents a comparison of engine CO g/km emissions with chassis transient emissions at several inertia weights. Vehicle 3-23 engine CO emissions were about 35 percent higher than chassis emissions. Chassis CO emissions increased slightly with an increase in inertia weight. Chassis and engine CO emissions did not agree at any inertia weight for Vehicle 3-23. Figure 15 also illustrates the relationship of the effect of inertia on CO chassis emissions from Vehicle 3-24 in comparison to the engine transient tests. Chassis CO emission rates (in g/km) increased significantly with an increase in inertia weight. Agreement of engine and chassis CO emissions for Vehicle 3-24 occurred at about 90 percent GVW.

The relationship between inertia weight and CO_2 emission rates (g/km) from Vehicles 3-23 and 3-24 is illustrated in Figure 16. Chassis CO_2 emission rates increased with increased inertia but never achieved the CO_2 emission rate of the engine test for Vehicle 3-23. At 70 percent of GVW, CO_2 emission rates (g/km) from engine and chassis tests agreed. The EPA-recommended practice for chassis transient testing also specifies using 70 percent GVW.

The effect of inertia on chassis NOx emission rates from Vehicles 3-23 and 3-24 is illustrated in Figure 17. Chassis NO_x emissions were about 30 percent less than engine NO_x emissions, at the inertia of best agreement (i.e., 100 percent GVW) for Vehicle 3-23. Chassis NO_x emissions increased with increasing inertia. Vehicle 3-24 chassis NO_x emissions increased significantly with an increase in inertia weight and engine-chassis agreement occurred at about 75 percent GVW.

Particulate emissions rates (in g/km), as a function of chassis inertia weights, are presented in Figure 18 for Vehicles 3-23 and 3-24. Particulate emission rates from Vehicle 3-23 are about 30 percent lower than the engine particulate rates. The increase in inertia only slightly increased the particulate emission rates from Vehicle 3-23. No agreement in particulate emission rates (in g/km) for Vehicle 3-23 engine and transient testing was observed. The engine and chassis particulate rates from Vehicle 3-24 were found to agree at an inertia weight of about 55 percent GVW.

Fuel specific emission rates are another method of comparing engine and chassis transient results. This method is based on emission rates per mass of fuel consumed, and essentially normalizes the chassis and engine cycle relative to fuel consumed, i.e., grams of emissions per kg fuel consumed. This comparison is more appropriate when the amount of work required is different between the two test procedures. This is the case when an engine capable of functioning satisfactorily in a dual-axle tractor is placed in a single-axle tractor. This occurred with Vehicle 3-23 which was powered by a Cummins NTC-300. The engine test procedure exercised the engine over a speed and load map based on what the engine is capable of producing; whereas, the chassis procedure required only the amount of power required to move the specific vehicle. In

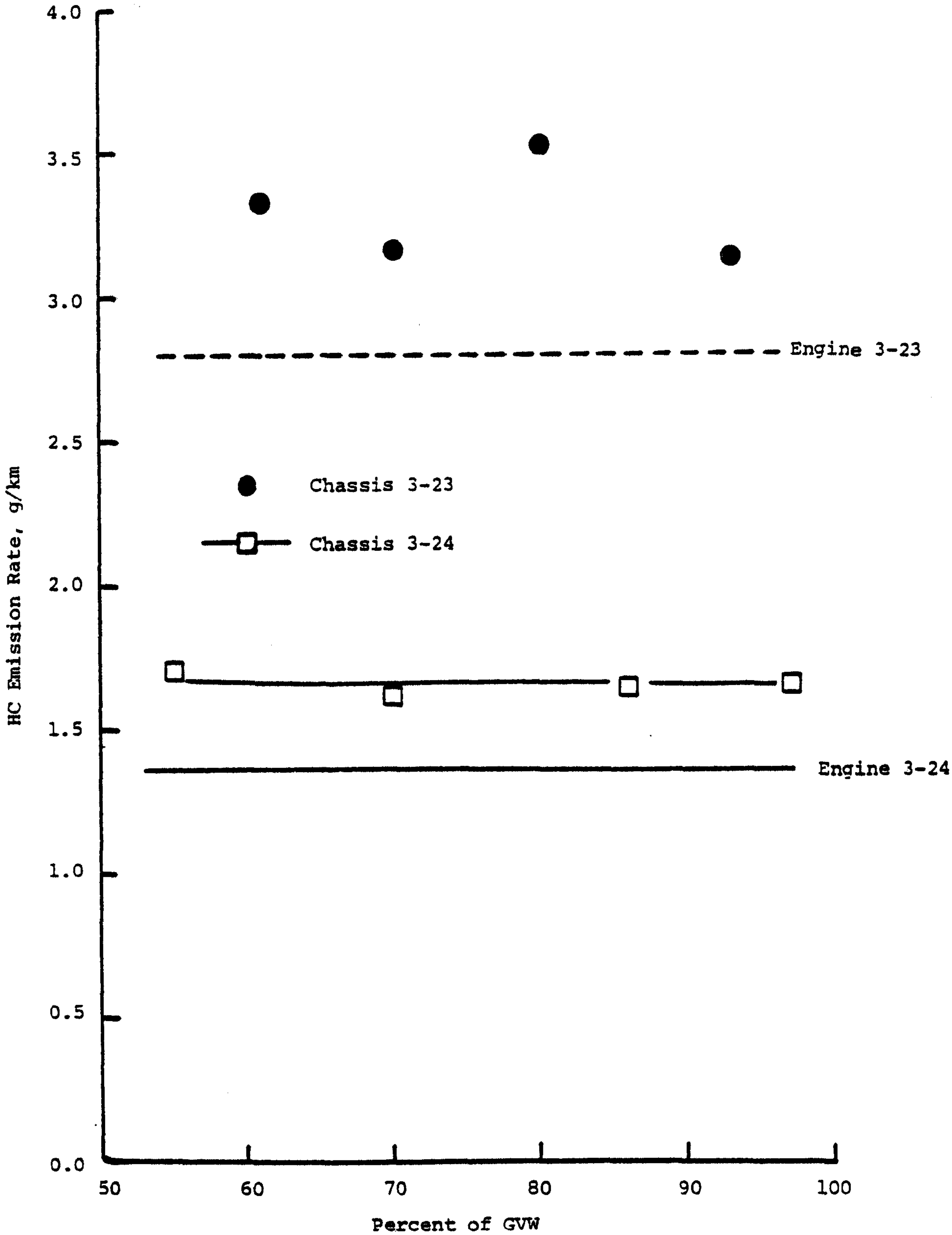


Figure 14. Comparison of HC emissions from engine tests and from chassis tests at several dynamometer settings

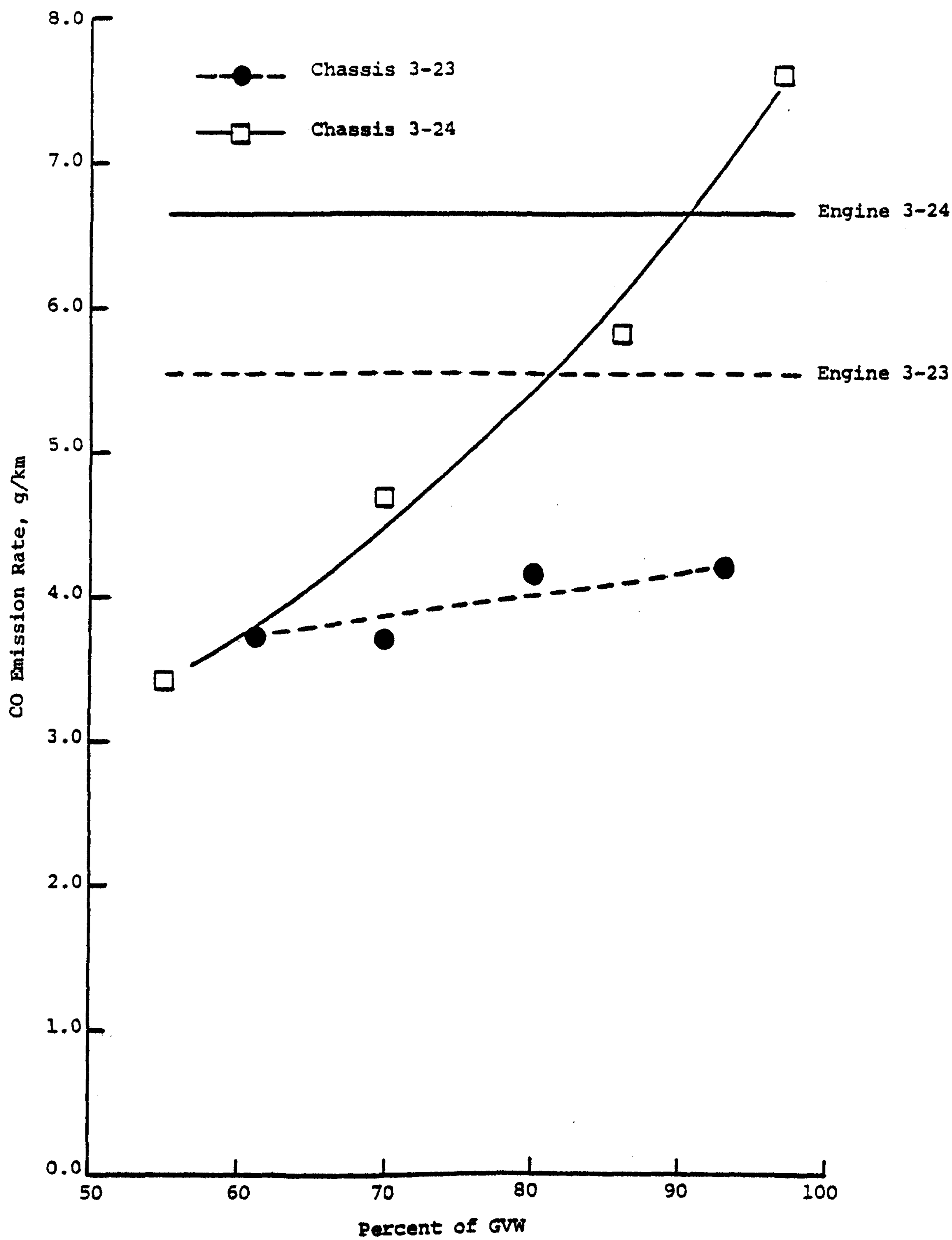


Figure 15. Comparison of CO emissions from engine tests and from chassis tests at several dynamometer settings

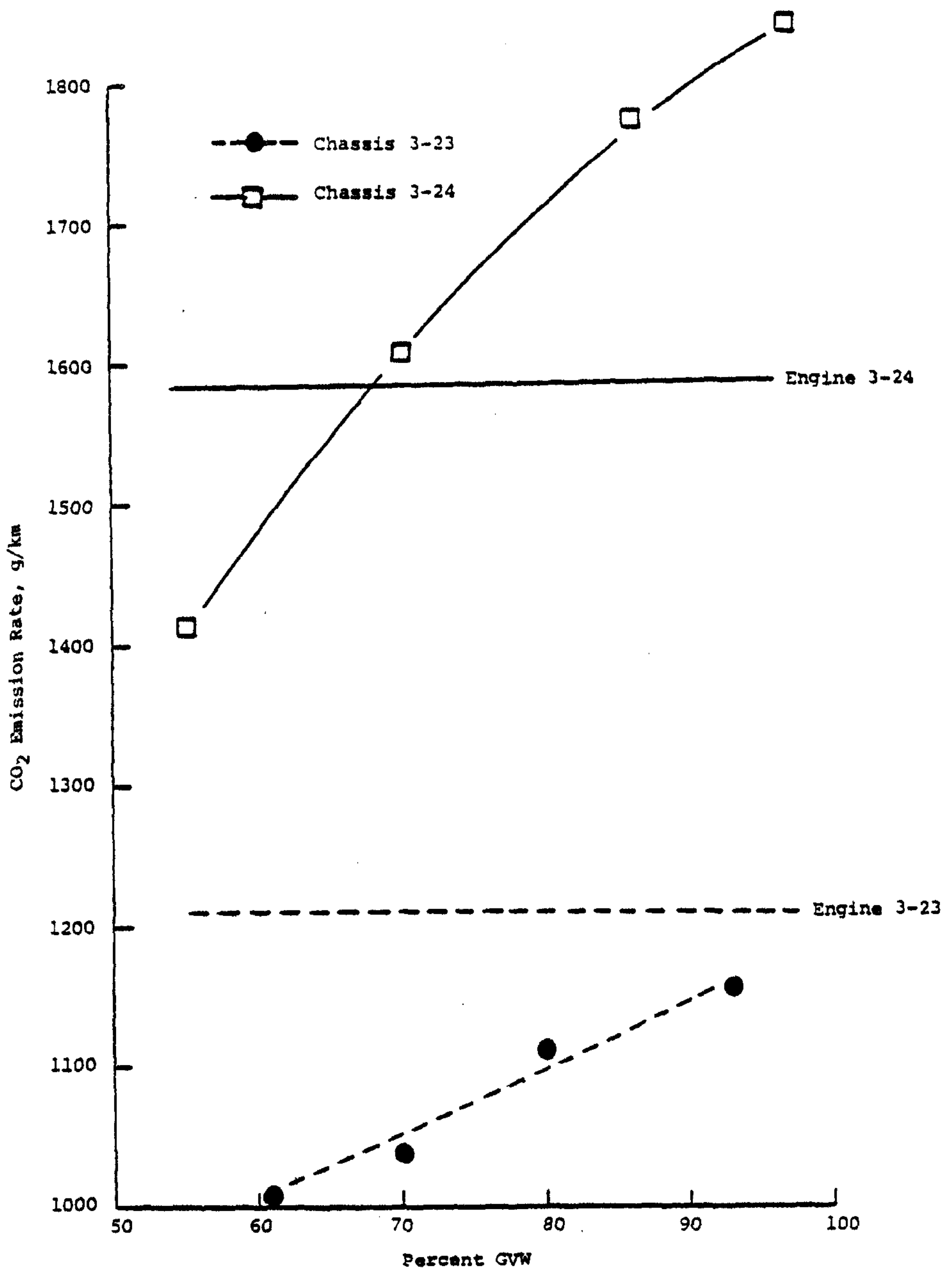


Figure 16. Comparison of CO_2 emissions from engine tests and from chassis tests at several dynamometer settings

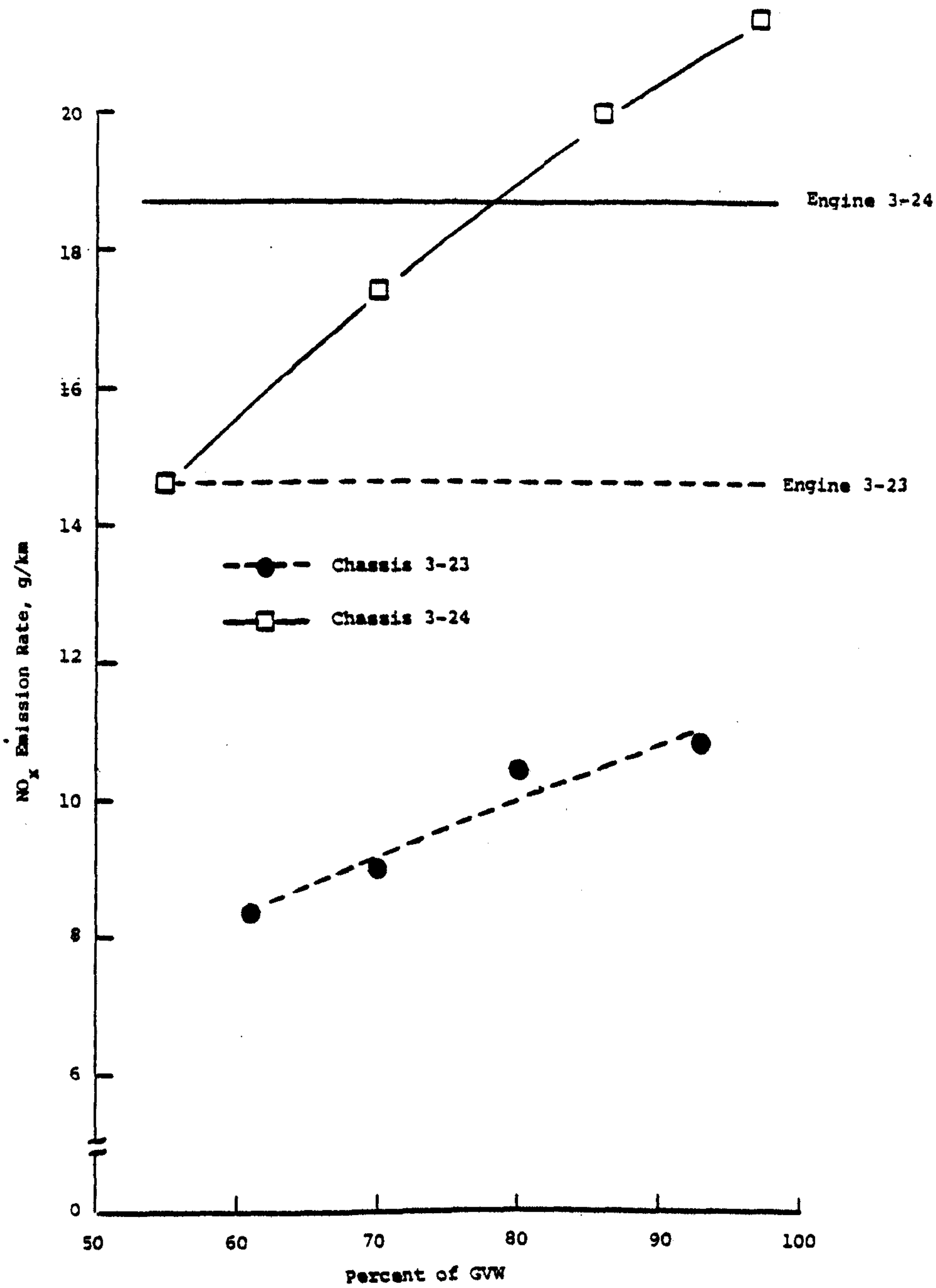


Figure 17. Comparison of NO_x emissions from engine tests and from chassis tests at several dynamometer settings

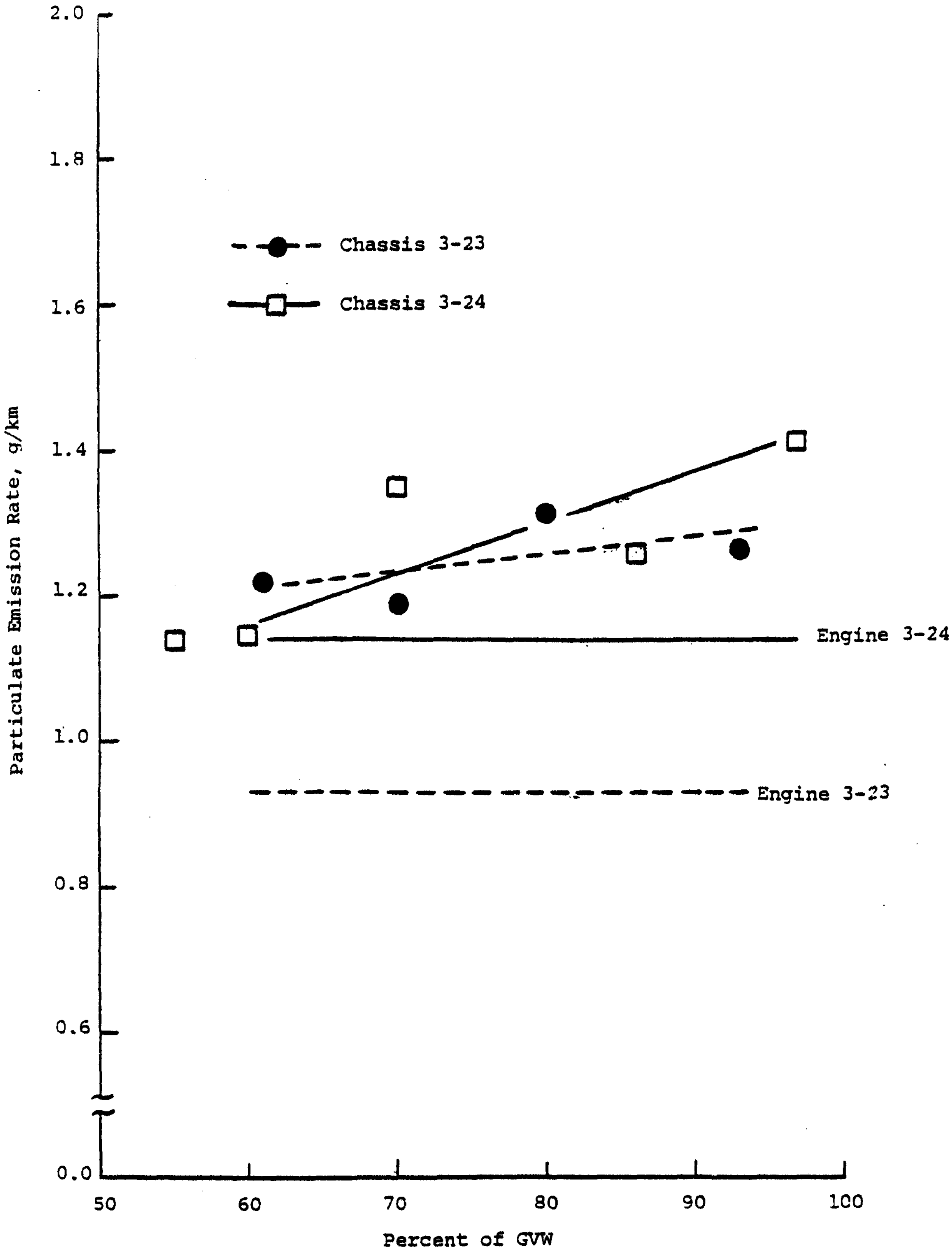


Figure 18. Comparison of particulate emissions from engine tests and from chassis tests at several dynamometer settings

the case of Vehicle 3-23 the engine is somewhat overpowered for the single-axle tractor and consequently only uses a portion of the power that it is capable of producing.

Figure 19 illustrates the relationship of inertia weight to HC fuel specific emission rates on Vehicles 3-23 and 3-24. Chassis HC emission rates from Vehicle 3-23 were about 15 percent higher than engine emission rates at best agreement. Chassis HC fuel specific-emission rates decreased with an increase in inertia weights for Vehicle 3-23. Engine and chassis HC fuel specific emission rates agreed at about 100 percent GVW for Vehicle 3-24.

Fuel specific CO emissions for Vehicles 3-23 and 3-24 are presented in Figure 20 for engine and chassis tests at several inertia weights. Vehicle 3-23 chassis CO emissions were 20 percent less than from the engine transient test. CO fuel specific emissions were only slightly affected by inertia weight. Increasing the inertia on Vehicle 3-24 was found to increase the CO fuel specific emissions significantly. Agreement of engine and chassis fuel specific CO emissions on Vehicle 3-24 occurred at about 100 percent of GVW.

The effect of inertia on fuel specific NO_x emissions from Vehicles 3-23 and 3-24 is illustrated in Figure 21. Fuel specific NO_x emissions from Vehicle 3-23 were observed to increase slightly with an increase in inertia, but even at the best agreement, chassis NO_x was about 30 percent less than the engine fuel specific NO_x. Agreement between chassis and engine fuel specific NO_x was found to occur at about 100 percent of GVW for Vehicle 3-24.

Particulate fuel specific emission rates for Vehicles 3-23 and 3-24 are illustrated in Figure 22. Chassis particulate emission rates decreased slightly with an increase in inertia, but even at best agreement chassis particulate was still about 50 percent higher than the engine transient particulate results. Although exact agreement between chassis and engine fuel specific particulate did not occur, best agreement was observed at 100 percent GVW.

Comparison of engine and chassis testing at several inertia weights have been presented in Figures 14-18 for g/km emission rates and in Figures 19-22 for fuel specific emissions (g/kg fuel). These results are summarized in Table 22 for Vehicle 3-23 and Table 23 for Vehicle 3-24. Engine versus chassis agreement for Vehicle 3-23 was poor at best. The chassis HC, CO and NO_x emissions were lower than the engine, while particulate emissions during chassis testing were higher. Although using fuel specific emissions for engine and chassis comparisons improved the numerical agreement, there was virtually no agreement from a practical standpoint.

Comparison of engine and chassis results from Vehicle 3-24 was more like what might be expected. When using g/km to compare engine versus chassis emissions, agreement at various inertias was observed. The inertia specified in the EPA-recommended practice is 70 percent of GVW. In the case of Vehicle 3-24, chassis and engine CO agreement occurred at 90 percent GVW, whereas, NO_x agreement was determined to be at 75 percent, and particulate from engine and chassis agreed at 55 percent of GVW. CO_2 agreement was observed at 70 percent of GVW for Vehicle 3-24. No agreement in HC g/km emission rates from Vehicle 3-24 could be determined.

Fuel specific emission rates from engine and chassis tests were found to agree when the chassis tests were conducted at about 100 percent of GVW. This was true for

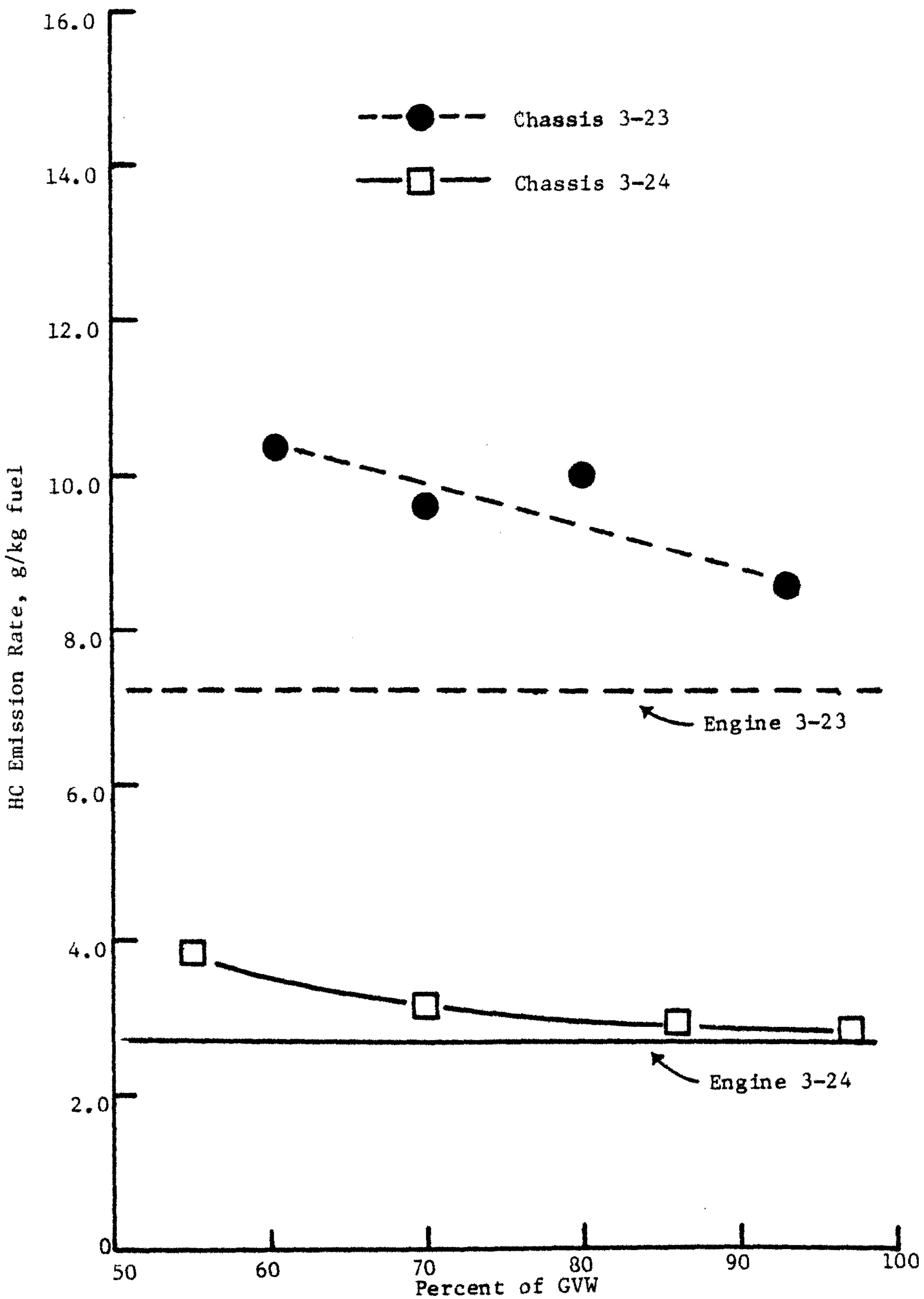


Figure 19. Comparison of fuel specific HC emission rates from engine and from chassis tests at several dynamometer settings

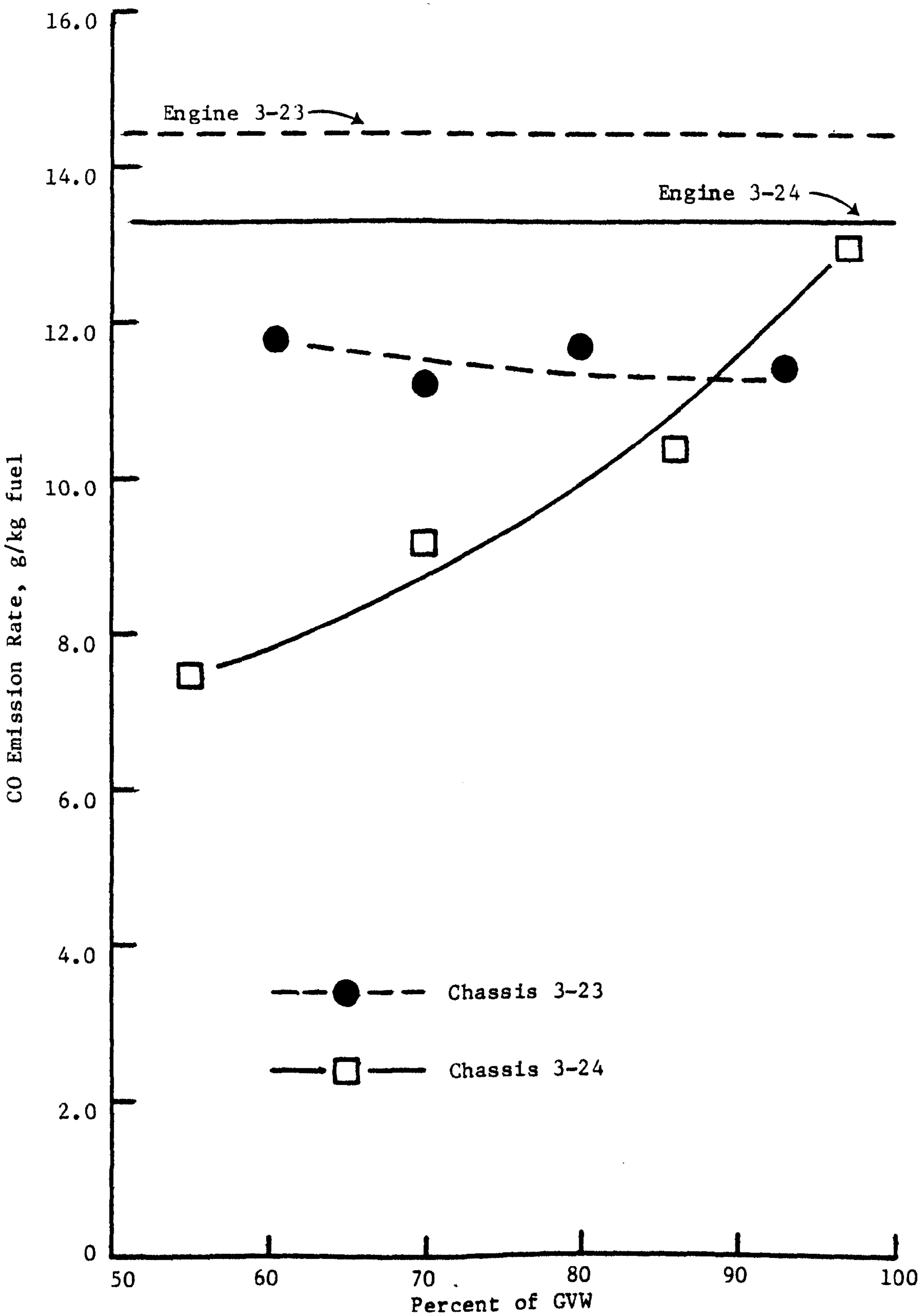


Figure 20. Comparison of fuel specific CO emission rates from engine tests and from chassis tests at several dynamometer settings

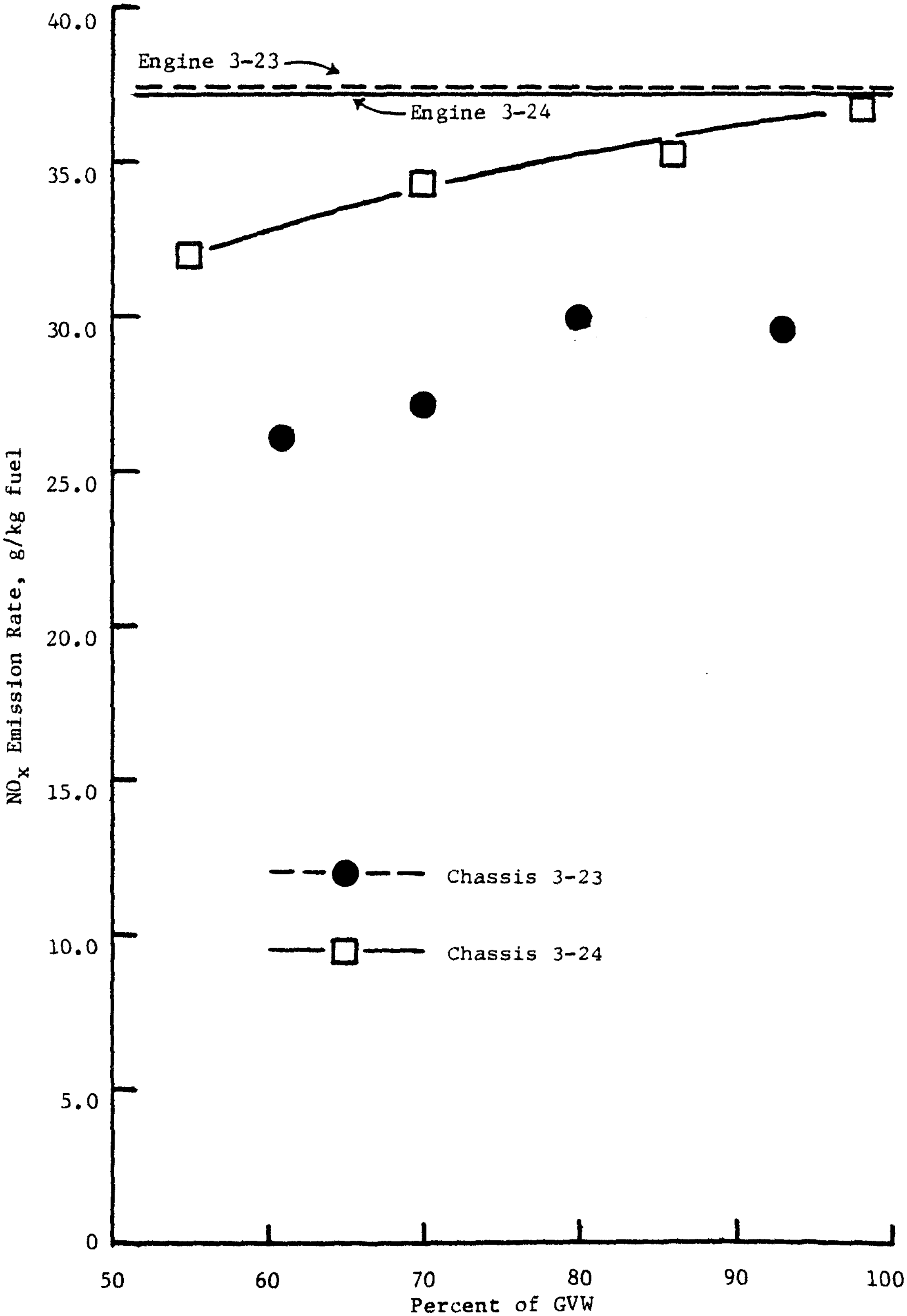


Figure 21. Comparison of fuel specific NO_x emission rates from engine tests and from chassis tests at several dynamometer settings

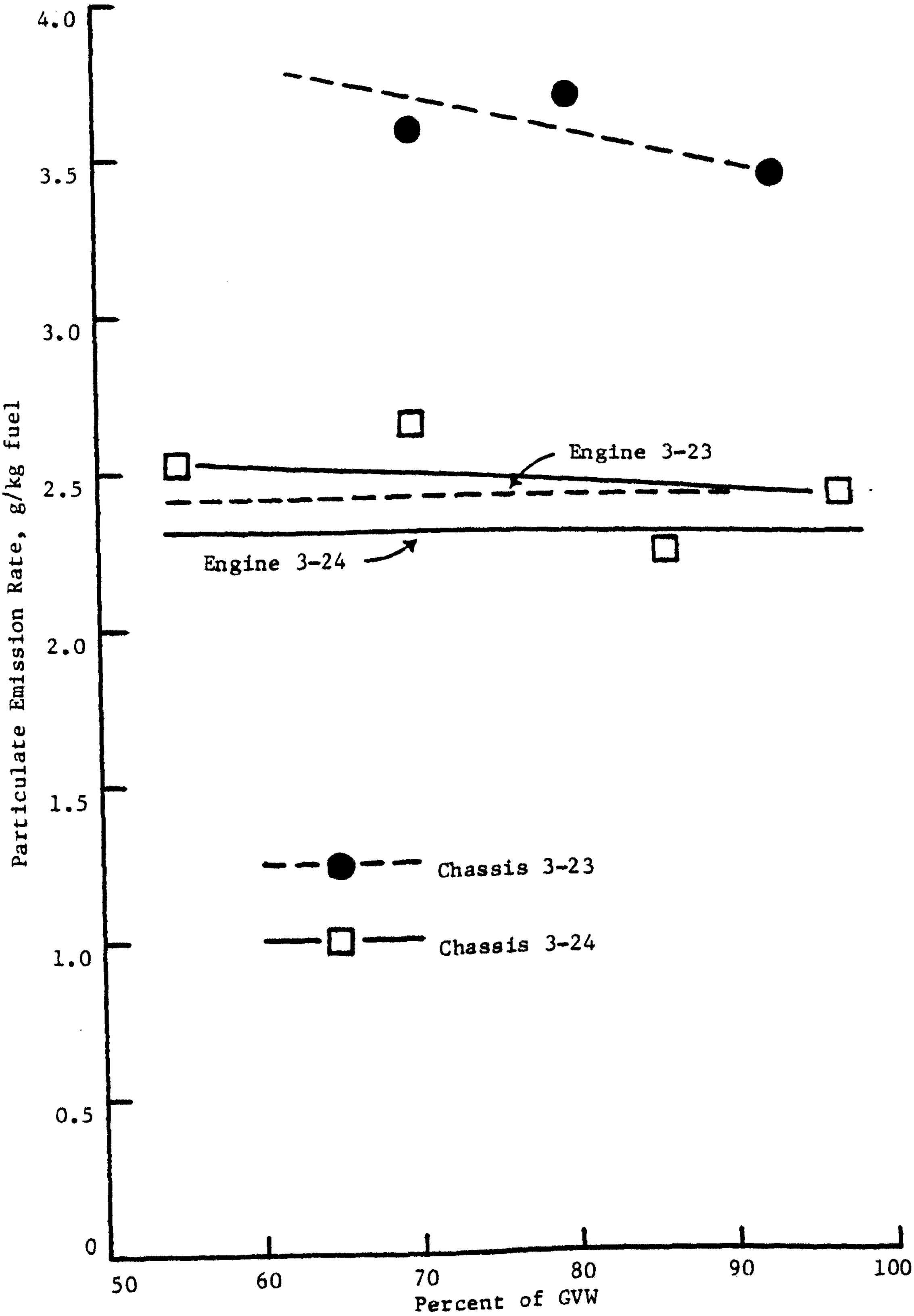


Figure 22. Comparison of fuel specific particulate emission rates from engine tests and from chassis tests at several dynamometer settings

TABLE 22. SUMMARY OF THE EFFECT OF INERTIA (PERCENT GVW) ON AGREEMENT BETWEEN CHASSIS AND ENGINE TRANSIENT EMISSIONS FOR VEHICLE 3-23

Exhaust	Emission Rate, g/km	Emission Rate, g/kg fuel
HC	chassis HC ≈ 20 percent higher than engine, GVW had little effect on HC, no HC agreement for engine and chassis tests	chassis HC decreased slightly with increasing GVW, chassis HC ≈ 15 percent higher than engine HC, no HC agreement for engine and chassis tests
CO	chassis CO increased slightly with inertia, chassis CO was ≈ 35 percent lower than engine, no CO agreement for engine and chassis tests	chassis CO was ≈ 20 percent less than engine CO, chassis CO only slightly affected by inertia, no CO agreement for engine and chassis tests
NO_x	chassis NO_x increased with increased inertia, but still significantly less than engine NO_x, chassis NO_x was ≈ 30 percent less than engine NO_x at best agreement	chassis NO_x increased slightly with increased inertia, but significantly less than engine NO_x by ≈ 27 percent at best agreement
Particulate	chassis particulate is ≈ 30 percent greater than engine particulate, chassis particulate increased only slightly with increased inertia, no particulate agreement for chassis and engine tests	chassis particulate is ≈ 50 percent higher than engine particulate, chassis particulate decreased with increasing inertia, no particulate agreement for chassis and engine tests

TABLE 23. SUMMARY OF EFFECT OF INERTIA (PERCENT GVW) ON AGREEMENT BETWEEN CHASSIS AND ENGINE TRANSIENT EMISSIONS FOR VEHICLE 3-24

Exhaust Species	Emission Rate, g/km	Emission Rate, g/kg fuel
HC	engine HC ≈ 20 percent higher than chassis, inertia had little effect on chassis HC, HC engine vs chassis emissions never agreed	HC chassis emissions decreased with increasing GVW, engine vs chassis agreement best at ≈ 100 percent GVW
CO	chassis CO significantly affected by GVW, best agreement of engine and chassis occurred at ≈ 90 percent GVW	fuel specific CO also significantly affected by GVW, best agreement of engine and chassis occurred at ≈ 100 percent GVW
NO_x	chassis NO_x emissions increase with increasing GVW, best agreement occurred at ≈ 75 percent GVW	chassis NO_x emissions increase with increasing GVW, best engine vs chassis agreement occurred at ≈ 100 percent GVW
Particulate	chassis particulate increased slightly with increasing GVW, best engine vs chassis agreement observed at ≈ 55 percent GVW	fuel specific particulate was only slightly affected by GVW, best agreement occurred at ≈ 100 percent GVW

HC, CO, NO_x and particulate emissions. Vehicle 3-24 was also tested at standard horsepower and at horsepower reduced by 20 percent to simulate operation of Vehicle 3-23. A comparison of hot-start chassis emissions of Vehicle 3-24 at standard and reduced horsepower is presented in Table 24. The tests involved only hot-starts and illustrate the effect of inertia at two horsepower settings for Vehicle 3-24. HC emission rates (g/km) were unaffected by horsepower or inertia. CO, CO_2, NO_x, and particulate emission rates (in g/km) increased with increasing inertia weights at both horsepower settings. CO, CO_2, NO_x, and particulate emissions were on average, lower when measured at reduced horsepower than at standard horsepower. Reduced horsepower CO was about 9 percent lower, CO_2 about 7 percent lower, NO_x about 10 percent lower, and particulate about 11 percent lower than at standard horsepower.

TABLE 24. SUMMARY OF EMISSIONS FROM HOT-START TESTS CONDUCTED ON VEHICLE 3-24 AT 55%, 70%, 86%, and 97% OF GVW AT STANDARD AND AT REDUCED HORSEPOWER

	Standard Horsepower					Reduced Horsepower[a]				
	Emission Rate, g/km					Emission Rate, g/km				
	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.
55%	1.74	3.37	1400	14.4	1.14	1.66	3.17	1324	12.9	1.07
70%	1.63	4.72	1596	17.6	1.36	1.68	4.13	1523	16.4	1.14
86%	1.64	5.92	1760	19.6	1.26	1.63	5.45	1596	17.3	1.11
97%	1.65	7.78	1833	21.5	1.40	1.66	7.11	1706	19.5	1.27
Avg.	1.67	5.45	1647	18.3	1.29	1.66	4.97	1537	16.5	1.15
S.D.[c]	0.05	1.87	192	3.0	0.12	0.02	1.71	161	2.8	0.09
C.V.[d]	3	34	12	17	9	1	34	10	17	8

[a]Reduced horsepower is 80 percent of standard horsepower
[b]NO_x from bag measurement
[c]Standard deviation
[d]Coefficient of variation, %

BASELINE STUDY

Regulated and several unregulated emissions were measured on 28 vehicles tested over the chassis transient cycle. Six buses, five single-axle tractors, and 17 dual-axle tractors were operated over at least two transient cycles. Fuel consumption was determined by two methods, the carbon balance calculation and Flo-tron measurement. NO_x was measured in Tedlar bags for all vehicles in the baseline study, and beginning with Vehicle 3-5, continuous NO_x measurement was added to the program.

Regulated Emissions and Particulates

Emissions data from individual baseline tests are given in Appendices B and C. A summary of composite chassis emissions from all Task 2 and Task 3 trucks is given in Table 25. Bus emissions are listed in Table 26, dual-axle tractor emissions in Table 27, and single-axle tractor emissions in Table 28. Average emission rate, standard deviation, and coefficient of variation for each emission have been calculated and are also given.

TABLE 25. SUMMARY OF EMISSION RATES OF TRUCKS TESTED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE

		Engine Description			Emission Rate, g/km					Emission Rate, g/kg fuel				
Task	Vehicle	Year	Manufacturer	Model	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.
2	2	1980	Cummins	Formula 350	2.06	5.56	1375	14.3	0.97	4.69	12.7	3145	32.7	2.21
2	3	1980	Detroit Diesel	8V-92TA	1.72	2.24	1424	13.4	0.87	3.81	4.97	3160	29.8	1.93
2	4	1979	Int'l Harvester	DT-466B	1.15	2.82	998	8.91	0.78	3.69	8.89	3154	28.1	2.50
3	1	1978	Cummins	Formula 350	2.18	3.76	1171	8.99	1.16	5.84	10.1	3145	24.2	3.11
3	2	1979	Int'l Harvester	DT-466	1.07	2.66	1008	10.8	0.81	3.36	8.30	3156	33.9	2.52
3	3	1977	Cummins	Formula 290	2.14	5.83	1066	9.15	1.43	6.28	17.1	3133	26.9	4.22
3	4	1980	Detroit Diesel	8V-92TA	1.65	3.07	1530	14.6	1.26	3.41	6.34	3159	30.2	2.60
3	5	1979	Detroit Diesel	8V-92TA	1.73	3.55	1634	16.2	1.19	3.34	6.86	3132	31.4	2.29
3	6	1979	Cummins	NTC-400	3.10	15.5	1508	14.1	1.88	6.41	31.9	3108	29.2	3.88
3	7	1981	Cummins	Formula 350	2.15	6.68	1348	15.3	1.16	5.00	15.6	3139	35.6	2.70
3	10	1981	Mack	EM6-285R	1.15	5.02	1268	17.5	1.47	2.88	12.5	3150	43.6	3.64
3	11	1980	Mack	EM6-285	0.95	5.39	1385	14.7	1.80	2.16	12.3	3155	33.4	4.10
3	12	1976	Caterpillar	3406 Economy	1.63	12.2	1516	18.6	2.85	3.35	25.1	3129	38.4	5.86
3	13	1982	Caterpillar	3406	1.23	8.02	1520	24.6	1.59	2.42	15.7	3147	48.3	3.13
3	14	1982	Cummins	Formula 350	1.81	7.43	1365	15.1	1.25	4.17	17.1	3140	34.8	2.87
3	15	1979	Cummins	Formula 350	2.05	19.8	1542	14.8	2.59	4.12	39.8	3103	29.8	5.22
3	16	1979	Cummins	NTC-290	1.37	5.63	1593	21.8	1.33	2.73	11.2	3154	43.2	2.64
3	17	1981	Cummins	Formula 350	1.78	6.45	1342	15.4	1.32	4.17	15.1	3142	36.0	3.15
3	18	1981	Cummins	NTC-300	1.57	4.56	1440	16.6	0.85	3.42	9.99	3152	36.3	1.85
3	19	1980	Cummins	NTC-300	2.06	6.51	1496	17.1	1.32	4.33	13.7	3144	36.1	2.78
3	23	1981	Cummins	NTC-300										
			61% of GVW, reduced HP		3.33	3.79	1006	8.37	1.22	10.4	11.8	3128	26.1	3.80
			70% of GVW, reduced HP		3.16	3.70	1036	8.99	1.19	9.60	11.2	3130	27.2	3.59
			80% of GVW, reduced HP		3.54	4.15	1110	10.4[b]	1.31	10.0	11.7	3128	30.0[b]	3.68
			93% of GVW, reduced HP		3.14	4.20	1152	10.8	1.26	8.55	11.4	3134	29.6	3.44
3	24	1980	Detroit Diesel	8V-92-TA										
			55% of GVW		1.71	3.36	1416	14.4	1.14	3.83	7.50	3156	32.1	2.53
			70% of GVW		1.62	4.67	1609	17.6	1.36	3.18	9.17	3155	34.4	2.64
			70% of GVW, reduced HP		1.68	4.13	1534	16.4	1.16	3.46	8.48	3155	33.7	2.37
			86% of GVW		1.65	5.81	1775	19.8	1.26	2.93	10.4	3154	35.2	2.24
			97% of GVW		1.66	7.62	1847	21.5	1.41	2.82	13.0	3150	36.7	2.41
				Average[c]	1.79	6.41	1372	14.9	1.38	4.20	14.4	3142	33.8	3.16
				Std. Dev.	0.57	4.30	200	4.0	0.52	1.66	8.3	15.2	5.9	1.01
				Coef. of Var. (%)	32	67	15	27	38	40	58	0.5	17	32
				Average, DD8V-92TA[d]	1.70	2.95	1529	14.7	1.11	3.52	6.06	3150	30.5	2.27
				Average, dual axle tractors	1.75	7.35	1455	16.4	1.48	3.74	15.3	3142	35.5	3.15

[a] NO_x from bag measurement
[b] NO_x is from test 32327 Run 2 only
[c] Average includes Vehicles 3-23 and 3-24 at 70% of GVW only
[d] Vehicles 2-3, 3-4, 3-5

TABLE 26. SUMMARY OF EMISSION RATES OF BUSES TESTED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE

		Engine Description			Emission Rate, g/km					Emission Rate, g/kg fuel				
Task	Vehicle	Year	Manufacturer	Model	HC	CO	CO_2	NO_x[a]	Part	HC	CO	CO_2	NO_x[a]	Part.
2	1	1980	Detroit Diesel	6V-71N	1.74	21.4	1262	10.8	1.28	4.23	51.9	3070	26.4	3.10
3	8	1980	Detroit Diesel	6V-71N	1.55	53.6	1192	10.2	4.42	3.85	132	2944	25.2	10.9
3	9	1980	Detroit Diesel	6V-71N	1.81	17.9	1202	13.8	1.44	4.65	45.8	3078	35.4	3.67
3	20	1980	Detroit Diesel	6V-71N	1.77	32.7	1234	10.2	3.61	4.35	79.8	3025	24.9	8.80
3	22	1978	Detroit Diesel	8V-71N	1.68	11.3	1277	17.0	1.54	4.08	27.4	3108	41.4	3.74
3	21	1979	Caterpillar	3208	0.68	2.90	750	11.0	0.96	2.84	12.1	3138	46.0	4.01
				Average[b]	1.71	27.4	1233	12.4	2.46	4.23	67.4	3045	30.7	6.04
				Std. Dev.	0.10	16.6	37	3.0	1.45	0.30	40.7	64	7.4	3.56
				Coef. of Var. (%)	6	61	3	24	59	7	60	2	24	59

[a] NO_x from bag measurement
[b] Average does not include Vehicle 3-21

TABLE 27. SUMMARY OF EMISSION RATES OF DUAL-AXLE TRACTORS TESTED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE

Task	Vehicle	Year	Manufacturer	Model	Emission Rate, g/km					Emission Rate, g/kg fuel				
					HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.
2	2	1980	Cummins	Formula 350	2.06	5.56	1375	14.3	0.97	4.69	12.7	3145	32.7	2.21
2	3	1980	Detroit Diesel	8V-92TA	1.72	2.24	1424	13.4	0.87	3.81	4.97	3160	29.8	1.93
3	4	1980	Detroit Diesel	8V-92TA	1.65	3.07	1530	14.6	1.26	3.41	6.34	3159	30.2	2.60
3	5	1979	Detroit Diesel	8V-92TA	1.73	3.55	1634	16.2	1.19	3.34	6.86	3132	31.4	2.29
3	6	1979	Cummins	NTC-400	3.10	15.5	1508	14.1	1.88	6.41	31.9	3108	29.2	3.88
3	7	1981	Cummins	Formula 350	2.15	6.68	1348	15.3	1.16	5.00	15.6	3139	35.6	2.70
3	10	1981	Mack	EM6-285R	1.15	5.02	1268	17.5	1.47	2.88	12.5	3150	43.6	3.64
3	11	1980	Mack	EM6-285	0.95	5.39	1385	14.7	1.80	2.16	12.3	3155	33.4	4.10
3	12	1976	Caterpillar	3406 Economy	1.63	12.2	1516	18.6	2.85	3.35	25.1	3129	38.4	5.86
3	13	1982	Caterpillar	3406	1.23	8.02	1520	24.6	1.59	2.42	15.7	3147	48.3	3.13
3	14	1982	Cummins	Formula 350	1.81	7.43	1365	15.1	1.25	4.17	17.1	3140	34.8	2.87
3	15	1979	Cummins	Formula 350	2.05	19.8	1542	14.8	2.59	4.12	39.8	3103	29.8	5.22
3	16	1979	Cummins	NTC-290	1.37	5.63	1593	21.8	1.33	2.73	11.2	3154	43.2	2.64
3	17	1981	Cummins	Formula 350	1.78	6.45	1342	15.4	1.32	4.17	15.1	3142	36.0	3.15
3	18	1981	Cummins	NTC-300	1.57	4.56	1440	16.6	0.85	3.42	9.99	3152	36.3	1.85
3	19	1980	Cummins	NTC-300	2.06	6.51	1496	17.1	1.32	4.33	13.7	3144	36.1	2.78
3	24	1980	Detroit Diesel	8V-92TA	1.62	4.67	1609	17.6	1.35	3.18	9.17	3155	34.4	2.64
				Average	1.74	7.19	1464	17.0	1.47	3.74	15.3	3142	35.5	3.15
				Std. Dev.	0.48	4.58	106	2.9	0.55	1.04	9.2	16	5.4	1.10
				Coef. of Var. (%)	28	64	7	17	37	28	60	1	15	35

[a] NO_x from bag measurement

TABLE 28. SUMMARY OF EMISSION RATES OF SINGLE-AXLE TRACTORS TESTED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE

		Engine Description			Emission Rate, g/km					Emission Rate, g/kg fuel				
Task	Vehicle	Year	Manufacturer	Model	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.
2	4	1979	Int'l Harvester	DT-466D	1.15	2.82	998	8.91	0.78	3.69	8.89	3154	28.1	2.50
3	1	1978	Cummins	Formula 350	2.18	3.76	1171	8.99	1.16	5.84	10.1	3145	24.2	3.11
3	2	1979	Int'l Harvester	DT-466	1.07	2.66	1008	10.8	0.81	3.36	8.30	3156	33.9	2.52
3	3	1977	Cummins	Formula 290	2.14	5.83	1066	9.15	1.43	6.28	17.1	3133	26.9	4.22
3	23[b]	1981	Cummins	NTC-300	3.16	3.70	1036	8.99	1.19	9.60	11.2	3130	27.2	3.59
				Average	1.94	3.75	1056	9.37	1.07	5.75	11.1	3144	28.1	3.19
				Std. Dev.	0.86	1.26	70	0.81	0.28	2.50	3.5	12	3.6	0.73
				Coef. of Var. (%)	44	34	7	9	26	44	32	<0.5	13	23

[a] NO_x from bag measurement

[b] Emissions obtained at inertia setting of 70% GVW. Vehicle 3-23 tested at 80 % of standard horsepower

Average emission rates were calculated for the five Detroit Diesel powered buses. Vehicle 3-21, a smaller bus powered by a lower horsepower Caterpillar engine, was not used in averaging. These data are listed separately in the Table. HC, CO, NO_x, and particulate emissions from all six buses are presented in bar charts in Figures 23, 24, 25, and 26, respectively. The emissions from the Caterpillar powered bus were lower than the average emissions from the other buses. HC and CO_2 emissions varied less than 10 percent for the Detroit Diesel powered buses. Vehicles 3-8 and 3-20 produced higher levels of CO and particulate. Vehicles 2-1 and 3-9 emitted lower levels of particulate, while Vehicles 3-9 and 3-22 produced higher levels of NO_x.

Emissions from single-axle tractors are summarized in Table 28 and in bar charts in Figures 27, 28, 29, and 30 for HC, CO, NO_x, and particulate. Less than 10 percent variation in CO_2 and NO_x emission rates (g/km) occurred among single-axle tractors. On a fuel specific basis, however, the variation in NO_x increased to 13 percent. Vehicles 2-4 and 3-2 emitted relatively low levels of HC, CO, and particulate. Of the five single-axle vehicles tested, Vehicle 3-3 produced the highest levels of CO and particulate, while Vehicle 3-23 produced the highest levels of HC.

HC, CO, NO_x, and particulate emissions from 17 dual-axle tractors are reported in bar charts in Figures 31 to 34, respectively, and in Table 27. The coefficient of variation in CO_2 levels among the tractors was less than 10 percent. The greatest differences were observed in CO emissions rates (coefficient of variation 64 percent). CO emissions varied from a low of 2.24 g/km to 19.8 g/km, with an average of 7.19 g/km. Vehicles 3-6, 3-12, and 3-15 emitted higher levels of CO and particulate. Vehicle 3-6 emitted the highest HC level of all dual-axle tractors tested. In general, variations in NO_x emissions were minor, with the exception of Vehicles 3-13 and 3-16. These vehicles produced NO_x emissions of 24.6 and 21.8 g/km, respectively, compared to the overall average of 17.0 g/km. Overall, emissions from dual-axle tractors were higher than. from single-axle tractors, with the exception of HC. Average HC from single-axle tractors was about 11 percent higher than the average HC emitted from dual-axle tractors.

Five of the six buses were operated over two cycles of the New York Bus Cycle, and HC, CO, CO_2, NO_x, and particulate emissions were measured. Emissions from individual tests are listed in Appendix F and a summary of the emissions is given in Table 29. HC, CO, CO_2, NO_x, and particulate emissions were averaged, and the standard deviation and coefficient of variation were calculated for all buses except Vehicle 3-21, which is a smaller bus powered by a lower horsepower engine. HC, CO, CO_2, and particulate emissions from Vehicle 3-21 were lower than emissions from the other buses. NO_x levels were more in line with the average NO_x produced by the other buses. CO_2 emission rates varied less than 10 percent for these four buses. Vehicles 3-8 and 3-20 produced higher CO and particulate while Vehicles 3-9 and 3-22 emitted lower CO. Vehicle 3-22 gave the highest NO_x emission rate.

Average bus emissions from the chassis transient cycle (Table 26) can also be compared to emissions from the New York Bus Cycle (Table 29). HC, CO, NO_x, and particulate emissions (in g/km) from the Bus Cycle exceeded transient cycle emissions by 30, 75, 23, and 58 percent, respectively. The variation in emission rates from the two cycles was less when emissions were reported in g/kg fuel. HC and NO_x emissions (in g/kg fuel) were essentially equivalent from the Bus and chassis transient cycles. CO emissions from the Bus Cycle were 42 percent higher than chassis transient CO and particulate emissions were 28 percent higher. For both sets of emissions units, g/km or

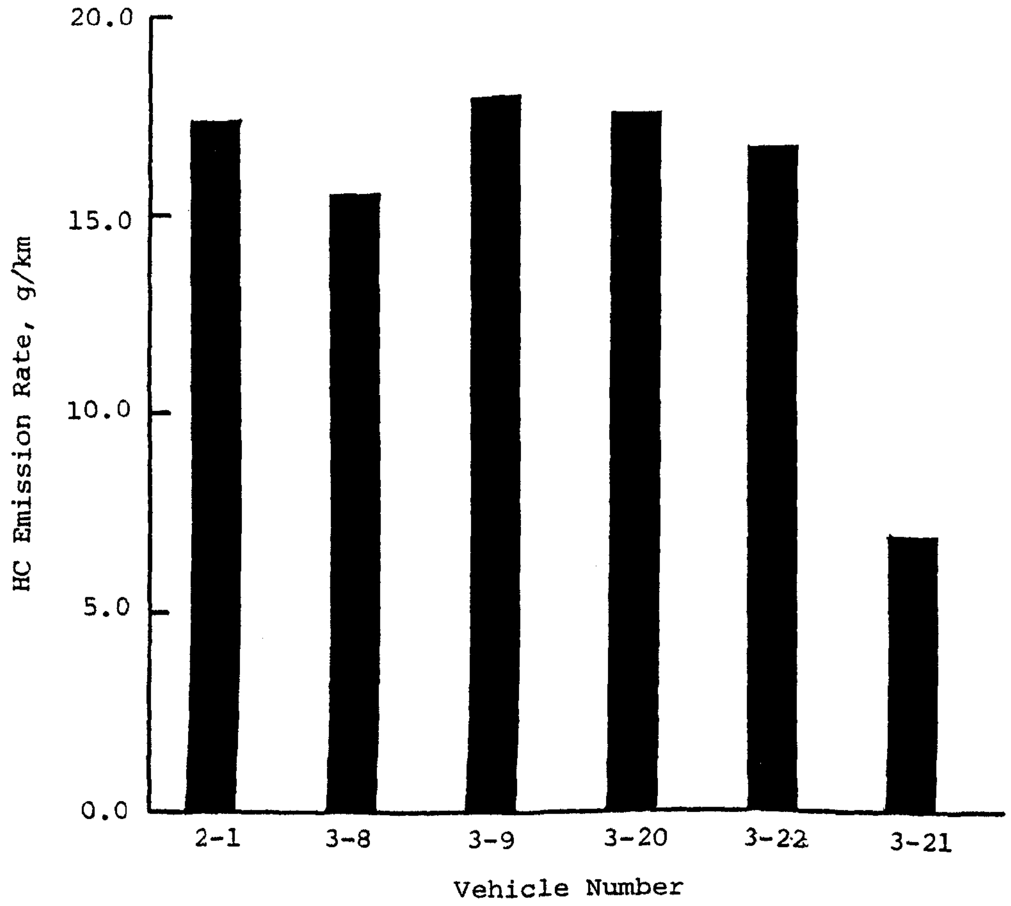


Figure 23. Comparison of HC emissions from six buses operated over the chassis version of the Transient Cycle

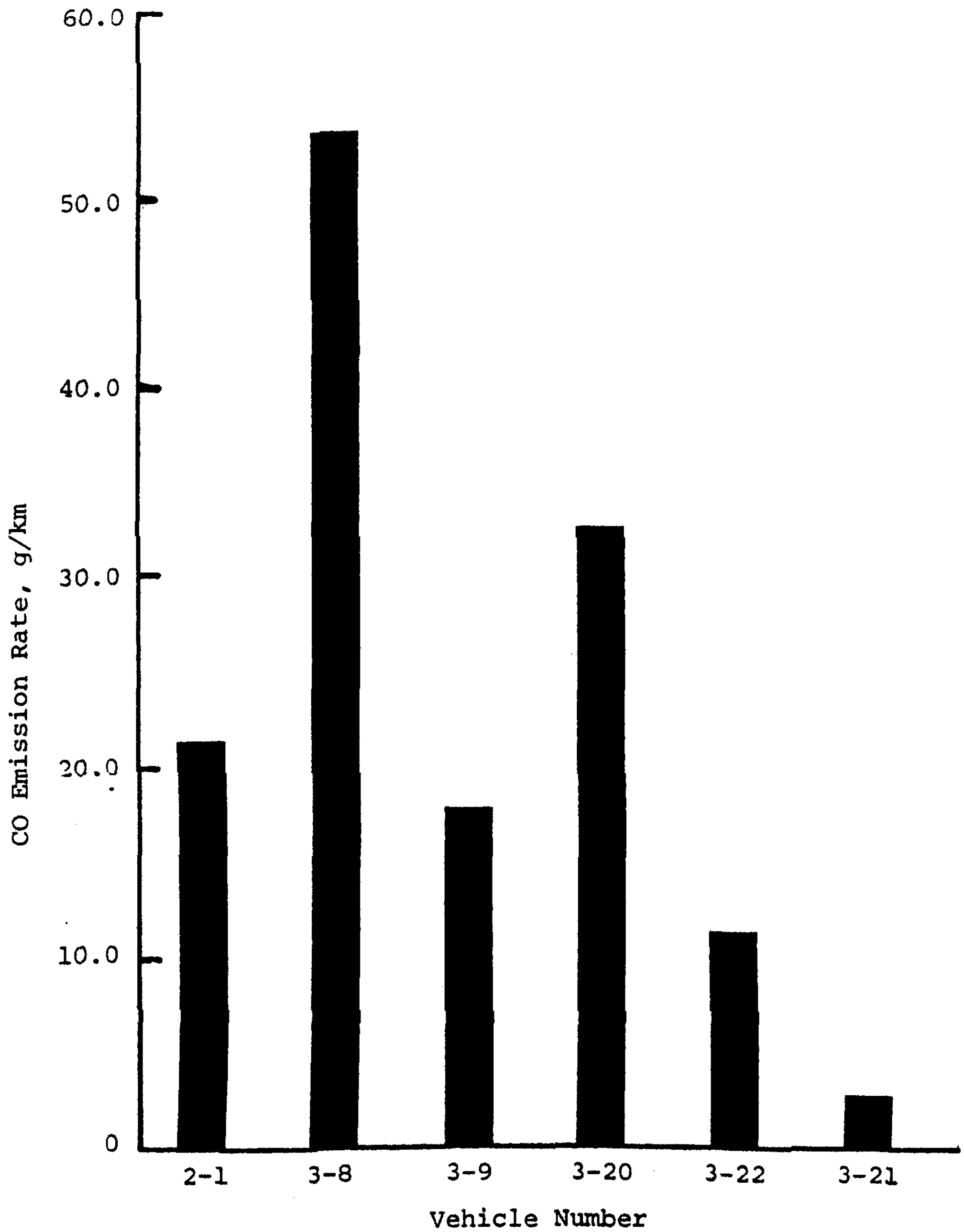


Figure 24. Comparison of CO emissions from six buses operated over the chassis version of the Transient Cycle

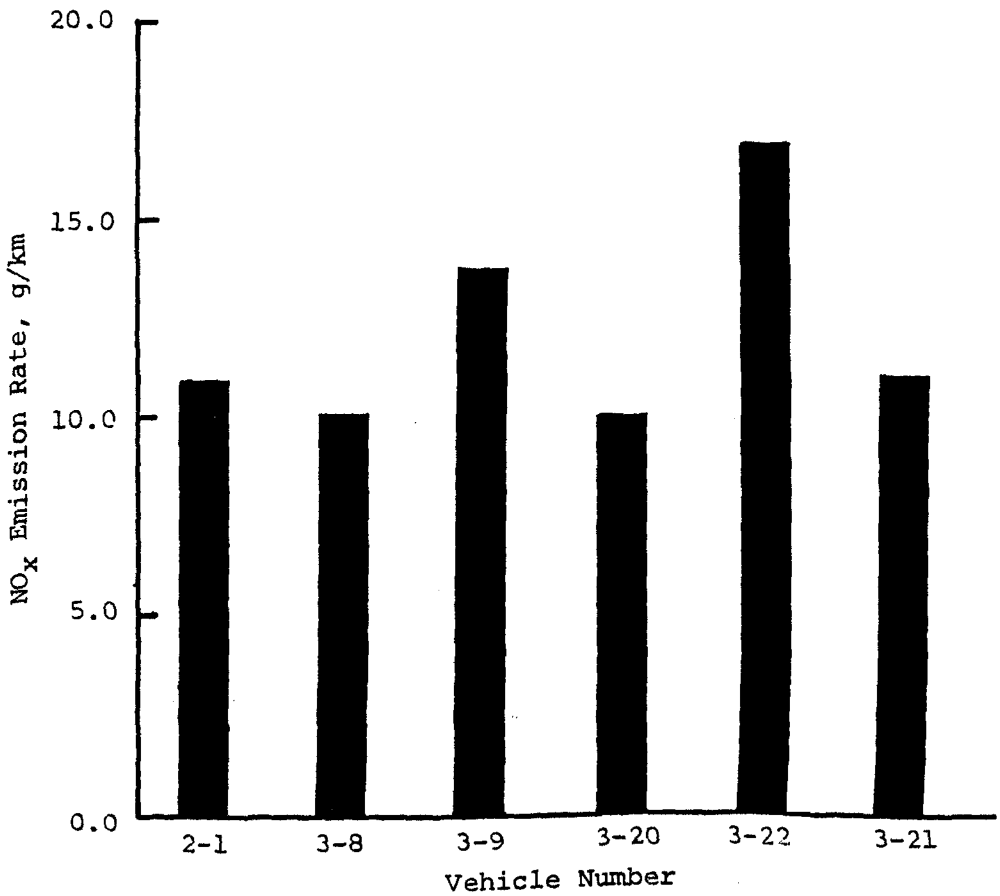


Figure 25. Comparison of NO_x emissions from six buses operated over the chassis version of the Transient Cycle

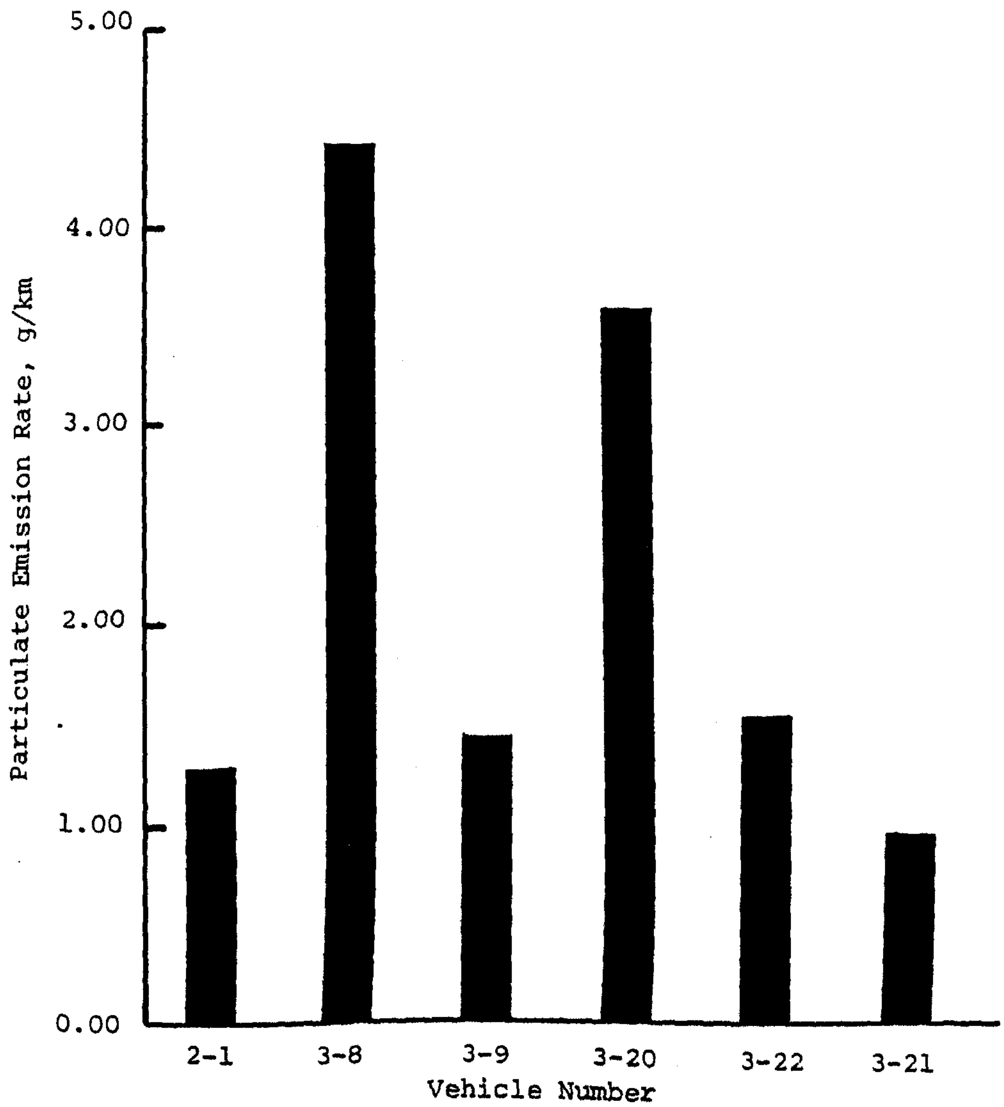


Figure 26 . Comparison of particulate emissions from six buses operated over the chassis version of the Transient Cycle

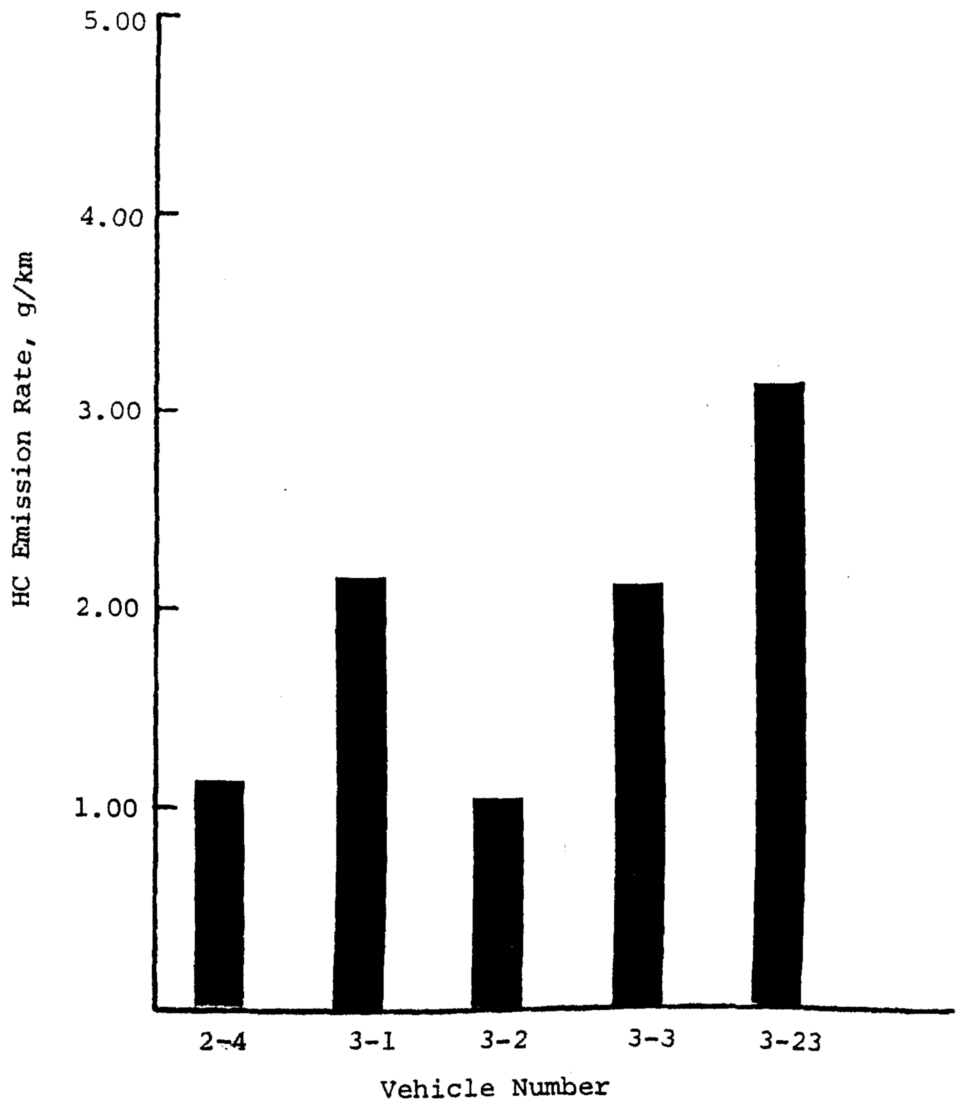


Figure 27. Comparison of HC emissions from five single-axle tractors operated over the chassis version of the Transient Cycle

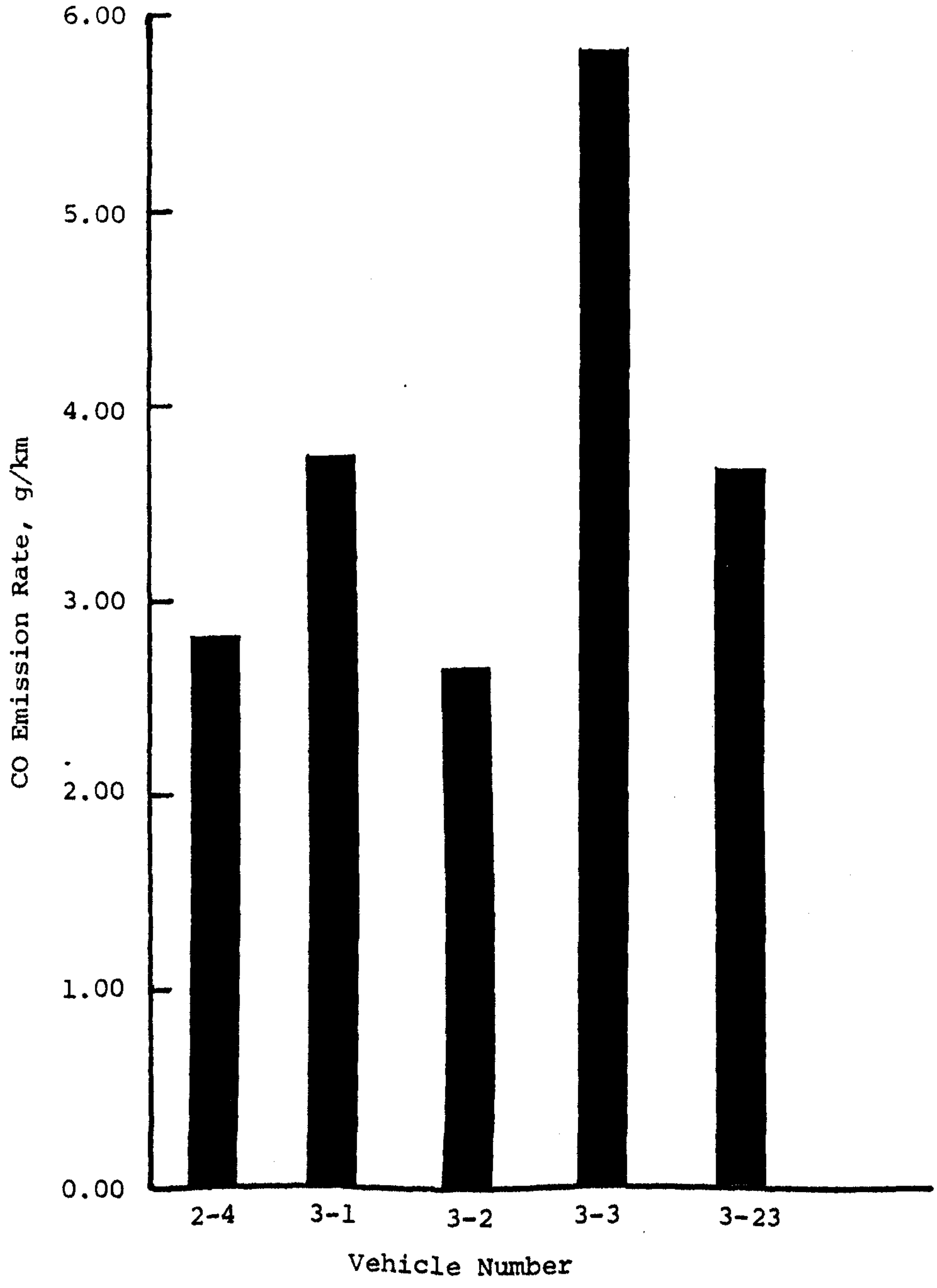


Figure 28. Comparison of CO emissions from five single-axle tractors operated over the chassis version of the Transient Cycle

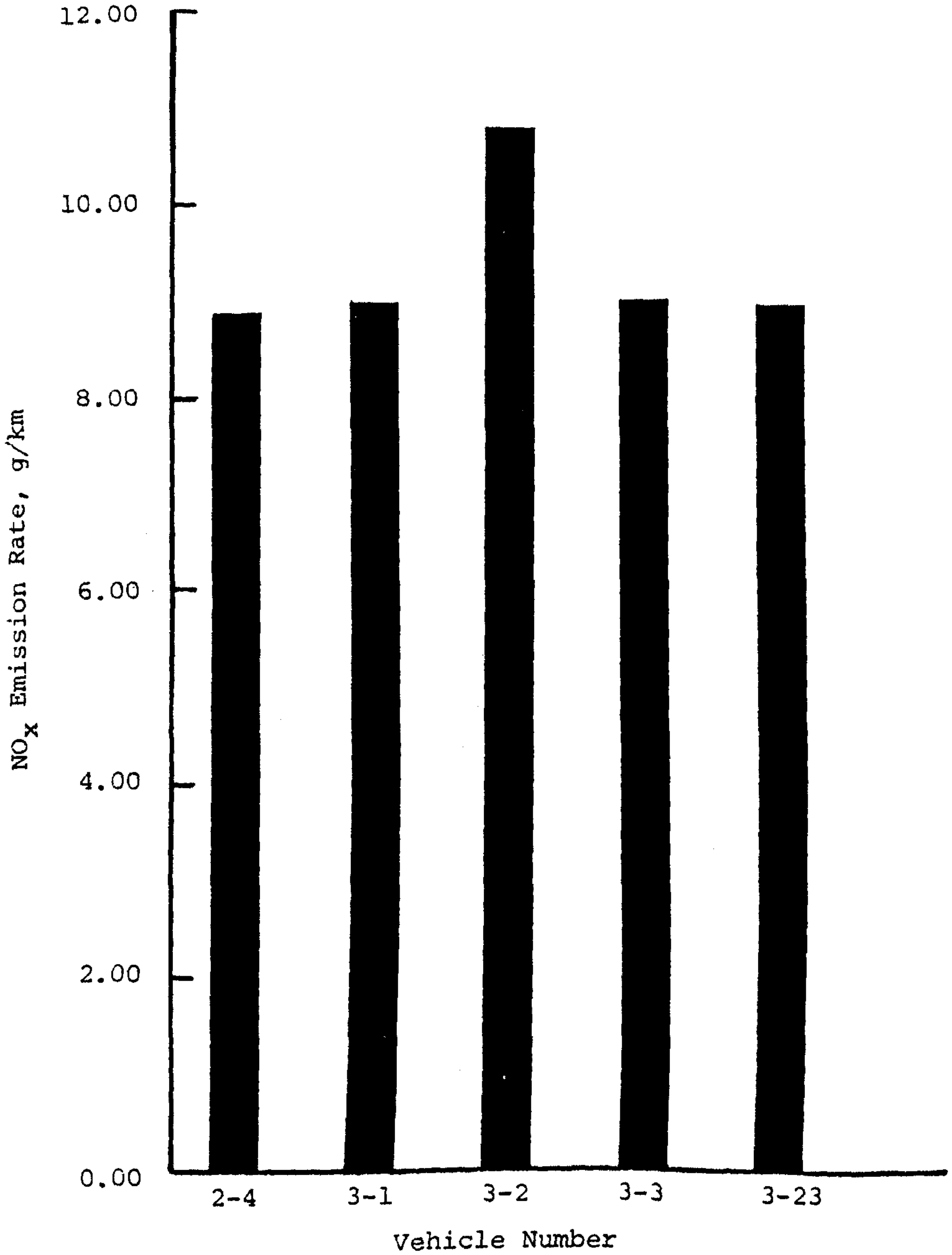


Figure 29. Comparison of NO_x emissions from five single-axle tractors operated over the chassis version of the Transient Cycle

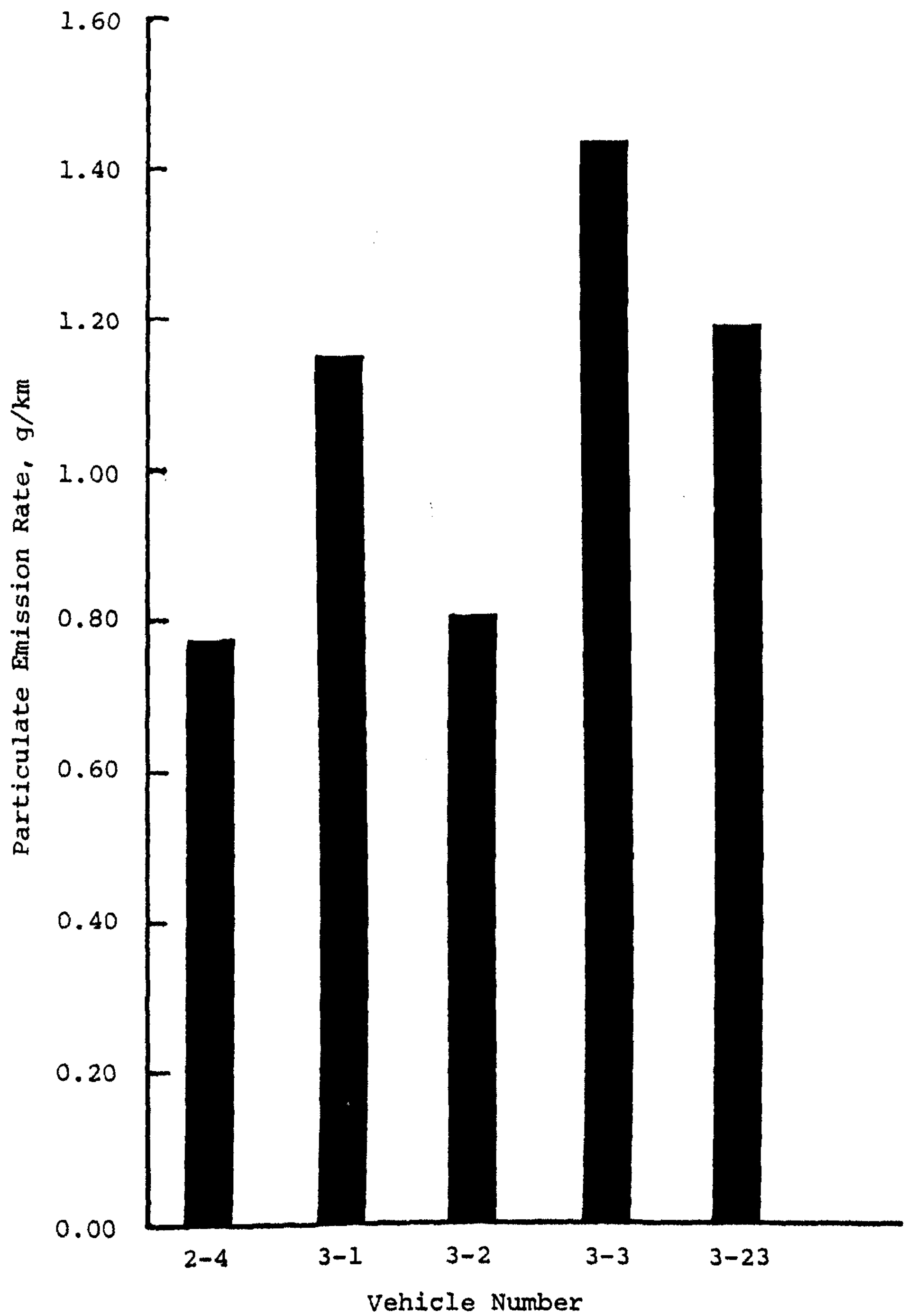


Figure 30. Comparison of particulate emissions from five single-axle tractors operated over the chassis version of the Transient Cycle

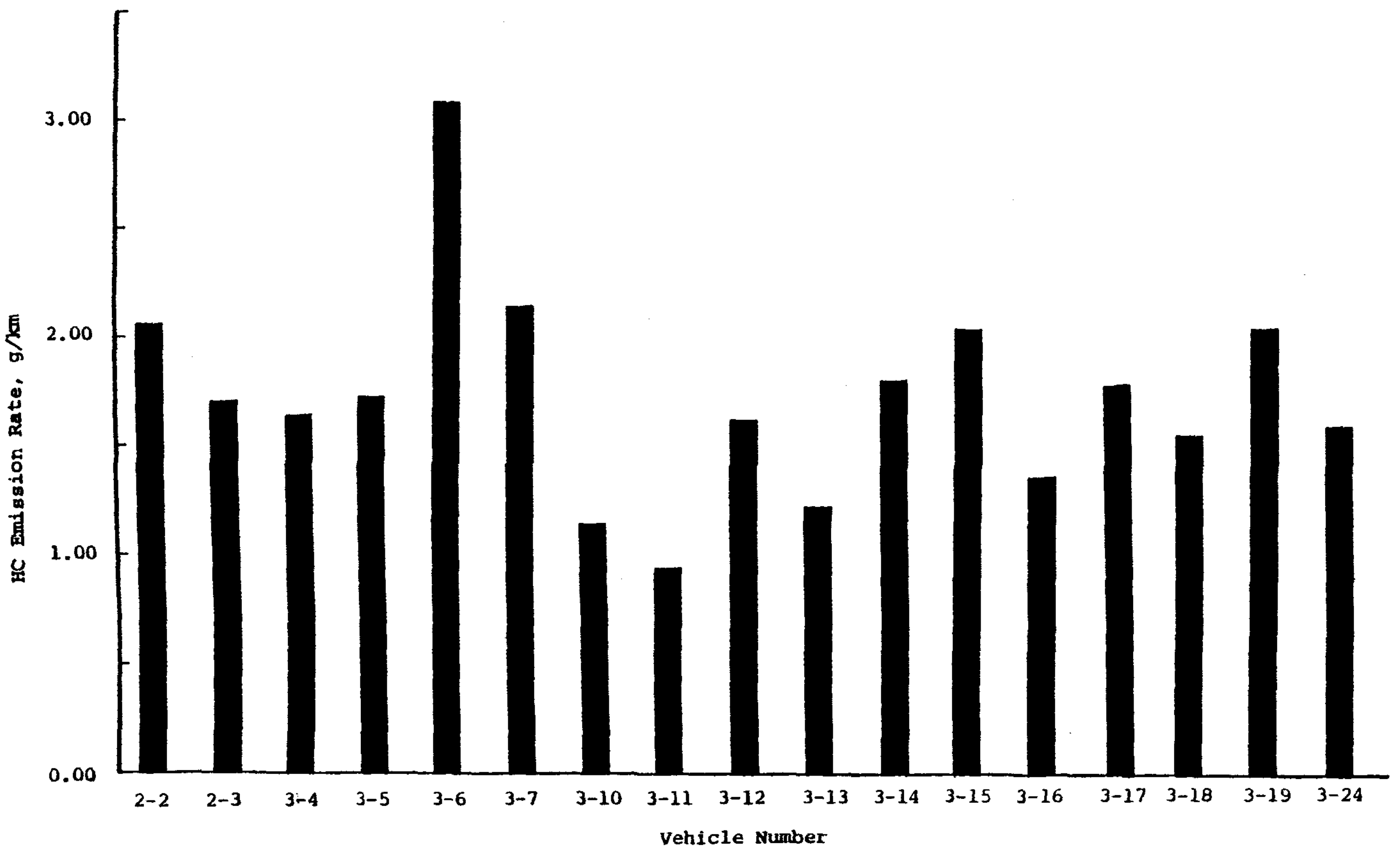


Figure 31. Comparison of HC emissions from 17 dual-axle tractors operated over the chassis version of the transient cycle

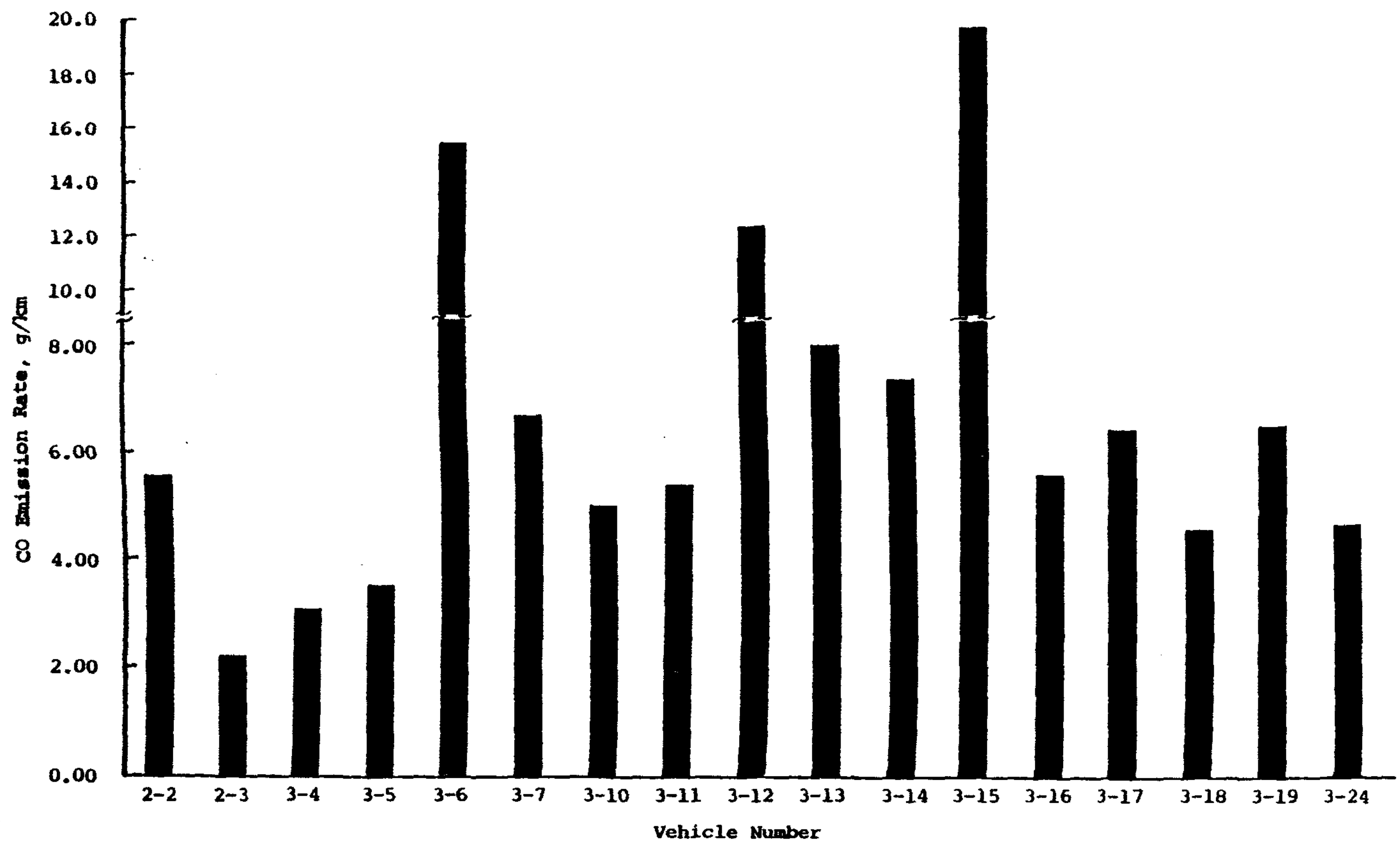


Figure 32. Comparison of CO emissions from 17 dual-axle tractors operated over the chassis version of the transient cycle

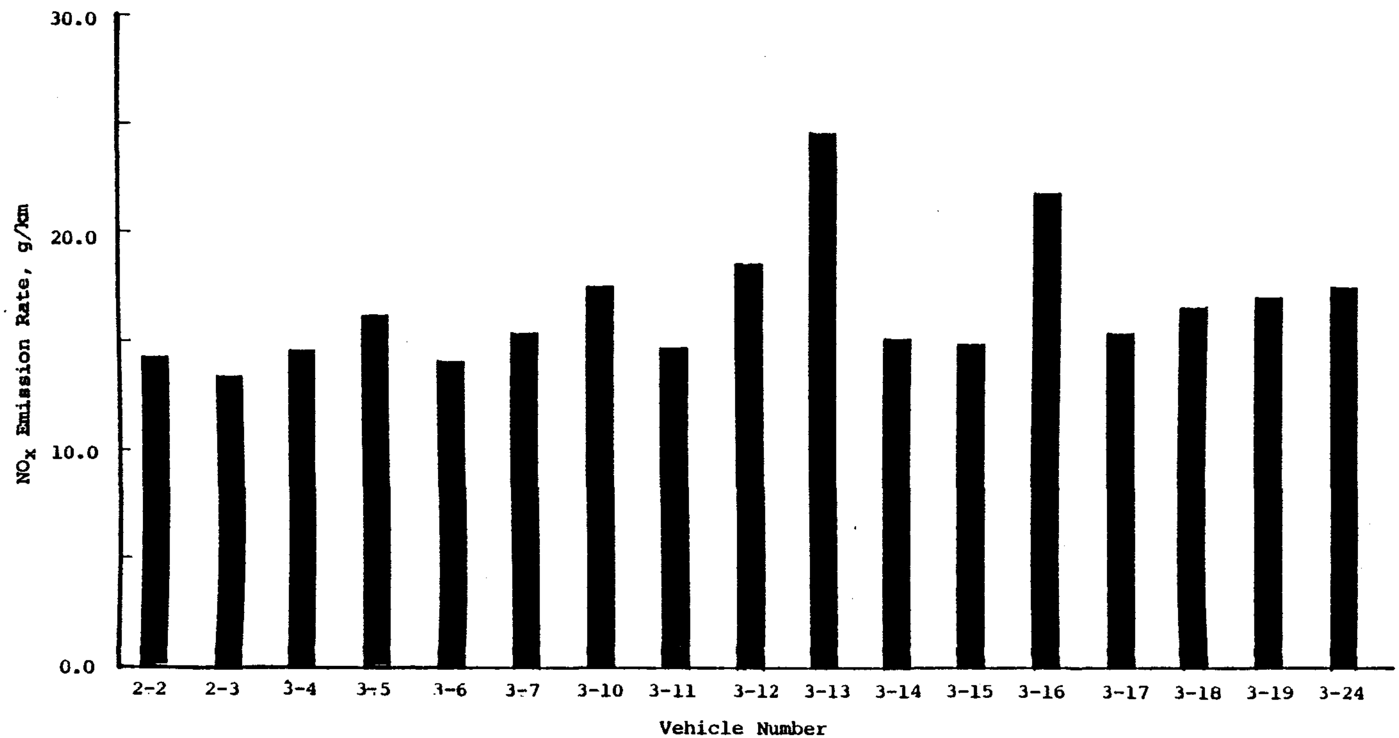


Figure 33. Comparison of NO_x emissions from 17 dual-axle tractors operated over the chassis version of the transient cycle

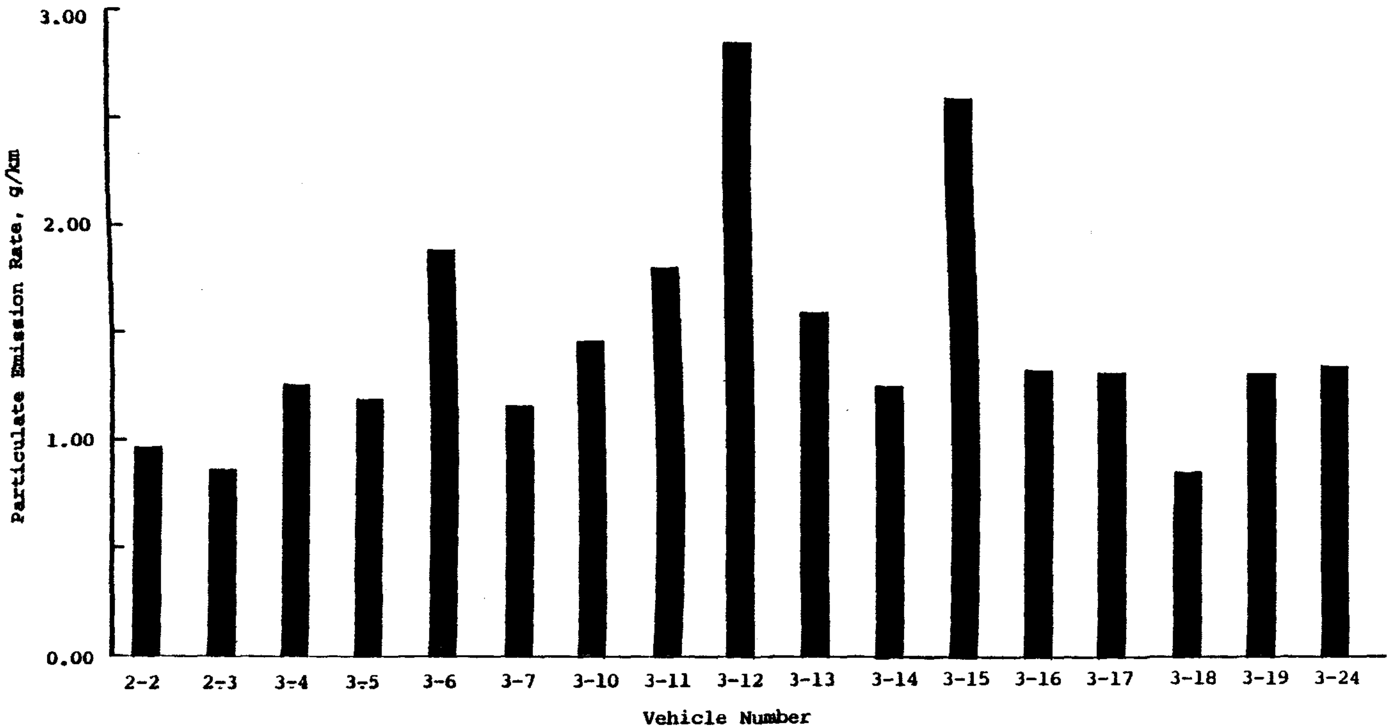


Figure 34. Comparison of particulate emissions from 17 dual-axle tractors operated over the chassis version of the transient cycle

TABLE 29. SUMMARY OF EMISSION RATES OF BUSES TESTED OVER THE NEW YORK BUS CYCLE

		Engine Description			Emission Rate, g/km					Emission Rate, g/kg fuel				
Task	Vehicle	Year	Manufacturer	Model	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.
3	8	1980	Detroit Diesel	6V-71N	2.26	79.6	1464	12.9	6.22	4.48	158	2902	25.6	12.3
3	9	1980	Detroit Diesel	6V-71N	2.50	32.0	1457	16.8	2.04	5.23	66.8	3044	35.1	4.25
3	20	1980	Detroit Diesel	6V-71N	1.78	63.6	1520	12.3	5.51	3.46	124	2960	24.0	10.7
3	22	1978	Detroit Diesel	8V-71N	2.38	17.0	1510	18.7	1.80	4.87	34.8	3094	38.2	3.69
3	21	1979	Caterpillar	3208	0.68	2.69	904	15.8	0.86	2.37	9.35	3142	54.9	2.99
				Average	2.23	48.0	1488	15.2	3.89	4.51	95.9	3000	30.7	7.74
				Std. Dev.	0.32	28.6	32	3.1	2.30	0.76	55.5	86	7.0	4.40
				Coef. of Var. (%)	14	60	2	20	59	17	58	3	23	57

[a] NO_x from bag measurement
[b] Average does not include Vehicle 3-21

g/kg fuel, CO and particulate emissions varied the most between driving cycles and HC and NO_x varied the least.

Carbon Balance Versus Measured Fuel Consumption Values

Fuel consumption was determined in two ways, by the carbon balance method[14] and by physical measurement during testing. The two sets of fuel consumption values are listed in Tables 30, 31, and 32 for buses, single-axle tractors, and dual-axle tractors, respectively. Composite fuel consumption and percent difference between calculated and measured fuel consumption have been calculated and are given in the tables.

Bar charts of fuel consumption data for buses, single-axle tractors, and dual-axle tractors are given in Figures 35, 36, and 37. Measured fuel consumption was usually greater than calculated fuel consumption. Lower calculated values are probably due to the limited ability of the instrumentation to measure all carbon-bearing emissions. Among the buses tested, the average measured fuel consumption exceeded average calculated fuel consumption by nine percent. With single-axle tractors the average measured fuel consumption was six percent higher, and with dual-axle tractors it was 2 percent higher than calculated values. The calculated fuel consumption for five of the buses (excluding Vehicle 3-21) varied between 48 and 51 liters/100 km. The range for single-axle and dual-axle tractors was greater, 38-44 liters/100 km and 48-61 liters/100 km, respectively. The average measured and calculated fuel consumption for buses, single-axle tractors and dual-axle tractors are compared in Figure 38. The average fuel consumption of buses (excluding Vehicle 3-21) was 54.2 liters/100 km measured and 49.9 liters/100 km calculated. For single-axle tractors average measured fuel consumption was 42.7 liters/100 km and calculated was 40.4 liters/100 km. Dual-axle tractors consumed fuel at the average rate of 57.0 liters/100 km measured and 55.7 liters/100 km calculated.

Continuous vs. Bag NO_x Measurements

NO_x in Tedlar bags was measured with all vehicles evaluated in this program. Continuous NO_x measurement was added during Task 3 for Vehicles 3-5 through 3-24, and the results are summarized in Table 33. Composite values have been calculated for each driving segment; NYNF, LANF, LAF, and NYNF, and as total NO_x for the entire test. Total continuous and bag NO_x are compared graphically in Figure 39. Continuously measured NO_x varied from three percent lower to 24 percent higher than bag NO_x, with an overall average of seven percent higher.

Unregulated Emissions

Several unregulated emissions were measured in the exhaust of Task 3 vehicles. Aldehydes and phenols were sampled in chilled impingers. Odor samples were collected on Chromosorb traps. Elemental composition and soluble organic fraction (methylene chloride extraction) were determined from particulate samples. The soluble organic fractions were subsequently analyzed for nitropyrenes and for mutagenic activity.

Aldehyde and ketone emissions are summarized in Table 34. Formaldehyde and acetaldehyde were the most prevalent of the aldehydes, accounting for 45 to 100 percent of the total measured aldehyde and ketone emissions.

TABLE 30. COMPARISON OF MEASURED VS CALCULATED FUEL CONSUMPTION FROM BUSES OPERATED OVER THE CHASSIS TRANSIENT CYCLE

Vehicle Number	Year	Vehicle & Engine Description: Manufacturer	Vehicle & Engine Description: Model	Test Number	Fuel Consumption, ℓ/100 km: Cold Start Meas'd	Cold Start Calc'd	Hot Start Meas'd	Hot Start Calc'd	Composite Meas'd	Composite Calc'd	Composite[a] Percent Difference
3-8	1980	GMC City Bus		3831	58.8	62.9	53.8	48.5	54.6	50.5	8%
		Detroit Diesel	6V-71N	3822	60.3	58.6	53.4	48.0	54.4	49.5	10%
				Avg.	59.6	60.8	53.6	48.2	54.5	50.0	9%
3-9	1980	GMC City Bus		3931	55.9	55.2	49.9	48.0	50.8	49.0	4%
		Detroit Diesel	6V-71N	3932	55.3	53.3	49.6	46.6	50.4	47.6	6%
				Avg.	55.6	54.2	49.8	47.3	50.6	48.3	5%
3-20	1980	GMC City Bus		32031	59.7	57.4	53.6	49.8	54.5	50.9	7%
		Detroit Diesel	6V-71N	32032	61.8	58.1	53.6	48.6	54.8	50.0	10%
				Avg.	60.8	57.8	53.6	49.2	54.6	50.4	9%
3-21	1979	Chance Mini Bus		32131	30.5	32.4	30.9	29.5	30.8	29.9	3%
		Caterpillar	3208	32132	34.5	31.8	31.9	28.8	32.3	29.3	10%
				Avg.	32.5	32.1	31.4	29.2	31.6	29.6	7%
3-22	1978	GMC City Bus		32231	62.3	57.1	56.0	49.3	56.9	50.4	13%
		Detroit Diesel	8V-71N	32232	63.4	56.5	56.1	50.2	57.2	51.1	12%
				Avg.	62.8	56.8	56.0	49.8	57.0	50.8	12%
								Avg.[b]	54.2	49.9	9%
								Std. Dev.	2.6	1.1	
								Coef. of Var.	5%	2%	

[a]Percent differences are calculated relative to the calculated fuel consumption
[b]Average fuel consumption does not include veh. 3-21, the small bus

TABLE 31. COMPARISON OF MEASURED VS CALCULATED FUEL CONSUMPTION FROM SINGLE-AXLE TRACTORS OPERATED OVER THE CHASSIS TRANSIENT CYCLE

Vehicle Number	Vehicle & Engine Description: Year	Manufacturer	Model	Test Number	Fuel Consumption, ℓ/100 km: Cold Start Meas'd	Cold Start Calc'd	Hot Start Meas'd	Hot Start Calc'd	Composite Meas'd	Composite Calc'd	Composite[a] Percent Difference
3-1	1978	Cummins	Formula	3121	49.8	47.7	48.2	43.5	48.4	44.1	10%
			350	3122	48.4	46.3	46.3	43.3	46.6	43.7	7%
				3123	49.8	47.6	46.9	44.0	47.3	44.5	6%
				Avg.	49.3	47.2	47.1	43.6	47.4	44.1	8%
3-2	1979	Int'l Harvester	DT-466	3221	41.9	40.1	40.4	37.3	40.6	37.7	8%
				3222	40.7	39.8	40.1	37.6	40.2	37.9	6%
				Avg.	41.3	40.0	40.2	37.4	40.4	37.8	7%
3-3	1977	Cummins	Formula	3321	45.4	44.8	42.2	40.1	42.6	40.8	5%
			290	3322	44.3	43.4	41.2	39.2	41.6	39.8	4%
				Avg.	44.8	44.1	41.7	39.6	42.1	40.3	4%
3-23	1981	Cummins	NTC-300	32325R-1	41.7	42.0	38.6	37.8	39.0	38.4	2%
		61% of GVW		32325R-2	41.1	41.4	38.1	37.0	38.5	37.6	2%
				Avg.	41.4	41.7	38.4	37.4	38.8	38.0	2%
		70% of GVW		32322	44.7	44.6	40.8	38.8	41.3	39.6	4%
				32324	43.9	42.6	40.1	38.0	40.6	38.7	5%
				Avg.	44.3	43.6	40.4	38.4	41.0	39.2	5%
		80% of GVW		32327R-1	45.0	44.2	41.7	42.5	42.2	42.7	-1%
				32327R-2	44.8	44.9	41.7	40.6	42.2	41.2	2%
				Avg.	44.9	44.6	41.7	41.6	42.2	42.0	0%
		93% of GVW		32326R-1	47.1	45.4	43.7	42.2	44.2	42.7	4%
				32326R-2	47.3	46.5	44.3	43.6	44.7	44.0	2%
					47.2	46.0	44.0	42.9	44.4	43.4	2%
								Avg.[b]	42.7	40.4	6%
								Std. Dev.	3.2	2.7	
								Coef. of Var.	7%	7%	

[a] Percent differences are calculated relative to the calculated fuel consumption
[b] Average includes fuel consumption of Vehicle 3-23 at 70% of GVW only

TABLE 32. COMPARISON OF MEASURED VS CALCULATED FUEL CONSUMPTION FROM DUAL-AXLE TRACTORS OPERATED OVER THE CHASSIS TRANSIENT CYCLE

Vehicle Number	Vehicle & Engine Description			Test Number	Fuel Consumption, ℓ/100 km						Composite[a] Percent Difference
	Year	Manufacturer	Model		Cold Start Meas'd	Cold Start Calc'd	Hot Start Meas'd	Hot Start Calc'd	Composite Meas'd	Composite Calc'd	
3-4	1980	Detroit Diesel	8V-92TA	3421	60.4	59.5	58.5	56.9	58.8	57.3	3%
				3422	62.1	59.8	60.6	57.0	60.3	57.4	6%
				Avg.	61.2	59.6	50.6	57.0	59.8	57.4	4%
3-5	1979	Detroit Diesel	8V-92TA	3521	64.1	64.3	63.2	61.9	63.4	62.2	2%
				3522	62.7	63.0	60.0	59.8	60.4	60.2	0%
				Avg.	63.4	63.6	61.6	60.8	61.9	61.2	1%
3-6	1979	Cummins	NTC-400	3621	58.4	63.5	56.6	56.4	56.8	57.4	-1%
				3622	59.3	61.7	56.8	56.7	57.1	57.4	0%
				Avg.	58.8	62.6	56.7	56.6	57.0	57.4	0%
3-7	1981	Cummins	Formula 350	3721	55.9	56.2	54.0	49.7	54.3	50.6	7%
				3722	53.9	55.4	50.3	50.1	50.8	50.9	0%
				Avg.	54.9	55.8	52.2	49.9	52.6	50.8	4%
3-10	1981	Mack	EM6-285R	31021	55.0	54.3	50.9	48.2	51.5	49.1	5%
				31022	53.6	54.4	45.9	44.8	47.0	46.2	2%
				Avg.	54.3	54.4	48.4	46.5	49.2	47.6	3%
3-11	1980	Mack	EM6-285	31121	52.7	54.1	51.1	51.0	51.3	51.4	0%
				31122	54.2	54.2	51.9	52.2	53.2	52.5	0%
				Avg.	53.4	54.2	51.5	51.6	51.8	52.0	0%
3-12	1976	Caterpillar	Economy 3406	31221	58.0	60.5	56.8	56.5	57.0	57.1	0
				31222	59.9	60.5	56.4	57.1	56.9	57.6	-1%
				Avg.	59.0	60.5	56.6	56.8	57.0	57.4	-1%
3-13	1982	Caterpillar	3406	31321	61.0	61.2	58.2	57.2	58.6	57.8	1%
				31322	66.2	66.1	62.5	62.2	63.0	62.8	0
				Avg.	63.6	66.6	60.4	59.7	60.8	60.3	1%
3-14	1982	Cummins	Formula 350	31421	56.9	54.6	53.3	51.3	53.8	51.7	4%
				31422	55.8	53.0	51.9	50.9	52.4	51.2	2%
				Avg.	56.4	53.8	52.6	51.1	53.1	51.4	3%
3-15	1979	Cummins	Formula 350	31521	62.5	62.6	62.3	59.1	62.4	59.6	5%
				31522	63.3	61.8	60.6	57.4	61.0	58.1	5%
				Avg.	62.9	62.2	61.4	58.2	61.7	58.8	5%

TABLE 32 (CONTINUED).

Vehicle Number	Year	Manufacturer	Model	Test Number	Fuel Consumption, ℓ/100 km: Cold Start Meas'd	Cold Start Calc'd	Hot Start Meas'd	Hot Start Calc'd	Composite Meas'd	Composite Calc'd	Composite[a] Percent Difference
3-16	1979	Cummins	NTC-290	31621	64.8	63.5	59.8	59.1	60.5	59.8	1%
				31622	65.9	64.1	61.7	59.8	62.3	60.4	3%
				31623	63.8	62.4	61.5	58.7	61.8	59.2	4%
				Avg.	64.8	63.3	61.0	59.2	61.5	59.8	3%
3-17	1979	Cummins	Formula 350	31721	57.5	53.8	49.3	49.8	50.5	50.4	0
				31722	57.7	53.7	53.7	50.2	54.3	50.7	7%
				Avg.	57.6	53.8	51.5	50.0	52.4	50.6	4%
3-18	1981	Cummins	NTC-300	31821	57.3	54.7	55.3	53.3	55.6	53.6	4%
				31822	58.7	49.8	56.6	54.2	56.9	53.6	6%
				Avg.	58.0	52.2	56.0	53.8	56.2	53.6	5%
3-19	1980	Cummins	NTC-300	31921	61.2	60.4	54.1	53.4	55.2	54.4	1%
				31922	61.8	60.3	58.7	57.9	59.2	58.2	2%
				Avg.	61.5	60.4	56.4	55.6	57.2	56.3	2%
3-24	1981	Detroit Diesel	8V-92TA								
		55% of GVW	Standard HP	32424R-1	59.2	56.7	56.6	52.7	57.0	53.3	7%
				32424R-3	58.9	56.8	55.1	52.3	55.6	52.9	5%
				Avg.	59.0	56.8	55.8	52.5	56.3	53.1	6%
		70% of GVW	Standard HP	32421R-1	64.7	62.8	61.8	59.7	62.2	60.1	4%
				32421R-2	64.8	63.6	61.6	60.1	62.0	60.6	2%
				Avg.	64.8	63.2	61.7	59.9	62.1	60.4	3%
			Reduced HP	32421R-3	62.2	60.1	58.5	57.2	59.0	57.6	2%
				42321R-4	62.3	60.3	58.5	57.1	59.0	57.5	3%
				Avg.	62.2	60.2	58.5	57.2	59.0	57.6	2%
		86% GVW	Standard HP	32422R-1	72.1	70.8	68.6	66.8	69.1	67.4	3%
				32422R-3	71.2	69.0	67.8	65.3	68.2	65.8	4%
				Avg.	71.6	70.0	68.2	66.0	68.6	66.6	4%
		97% GVW	Standard HP	32423R-1	75.9	73.4	71.6	69.5	72.2	70.0	3%
				32423R-3	73.9	71.6	70.6	68.3	71.1	68.8	3%
					74.9	72.5	71.1	68.9	71.6	69.4	3%
								Average[b]	57.0	55.7	2%
								Std. Dev.	4.3	4.3	
								Coef. of Var.	8%	8%	

[a] Percent differences are calculated relative to the calculated fuel consumption
[b] Average includes Vehicle 3-24 at 70% of GVW only

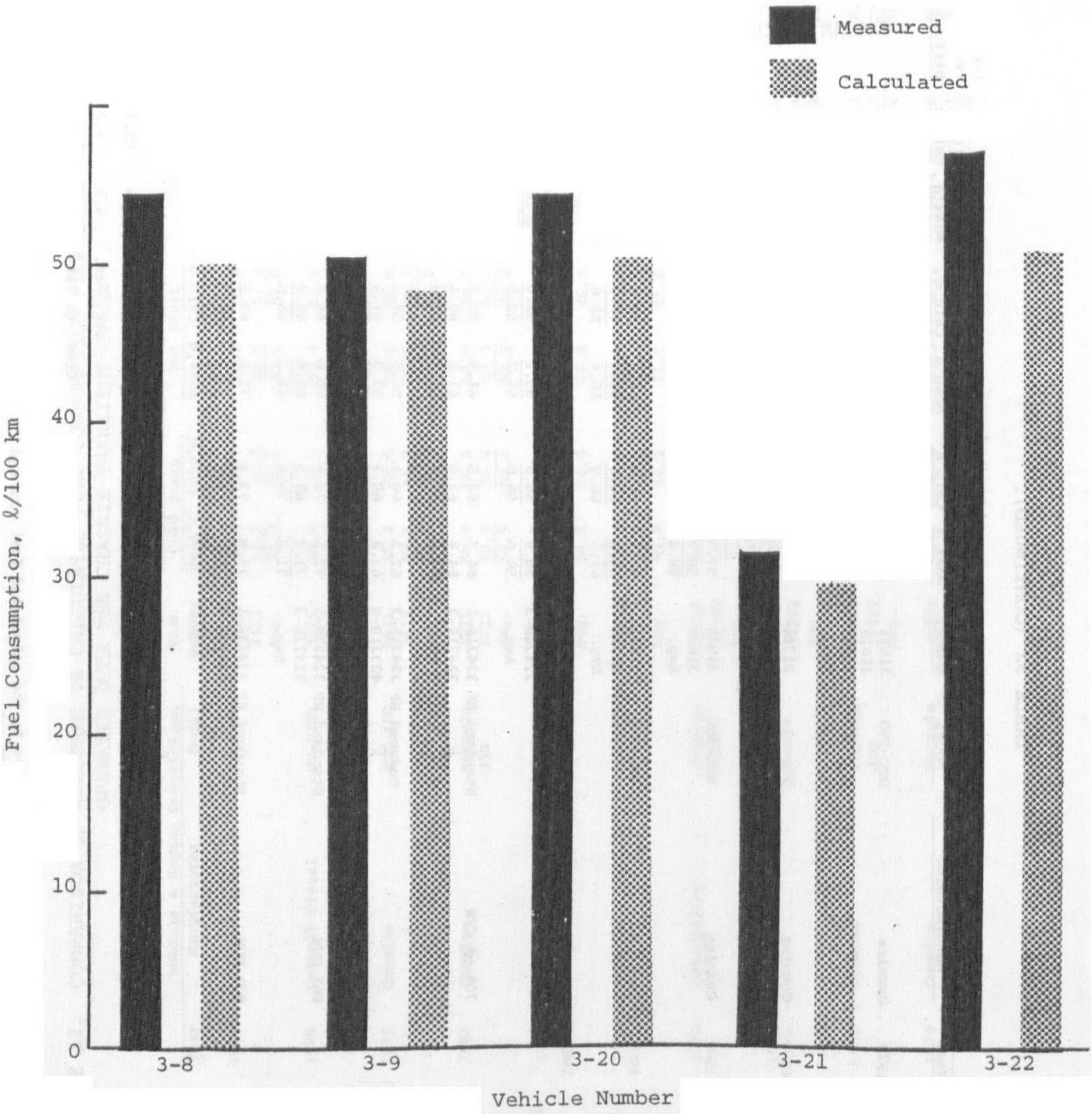


Figure 35. Comparison of measured and calculated fuel consumption of buses

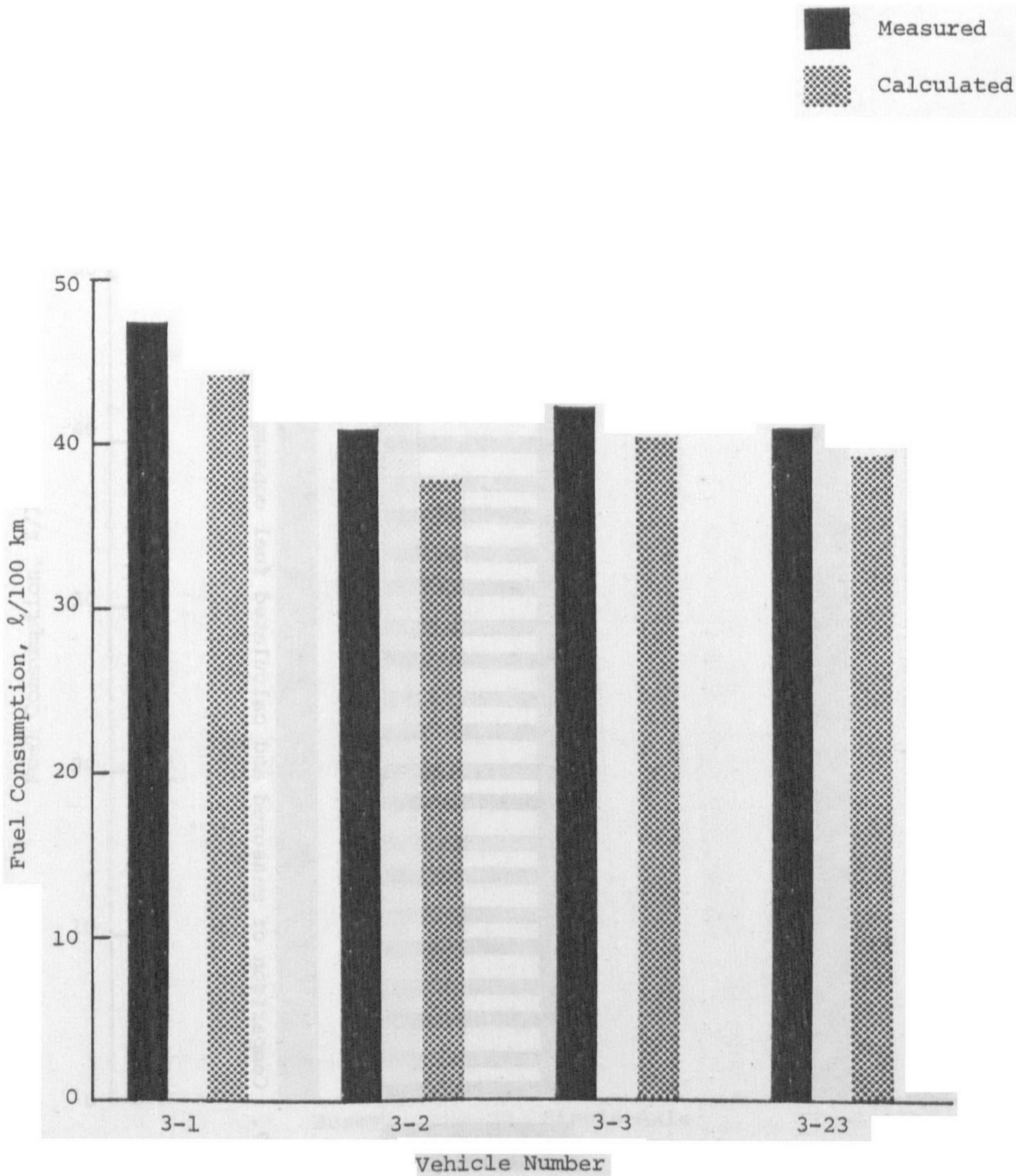


Figure 36. Comparison of measured and calculated fuel consumption of single-axle tractors

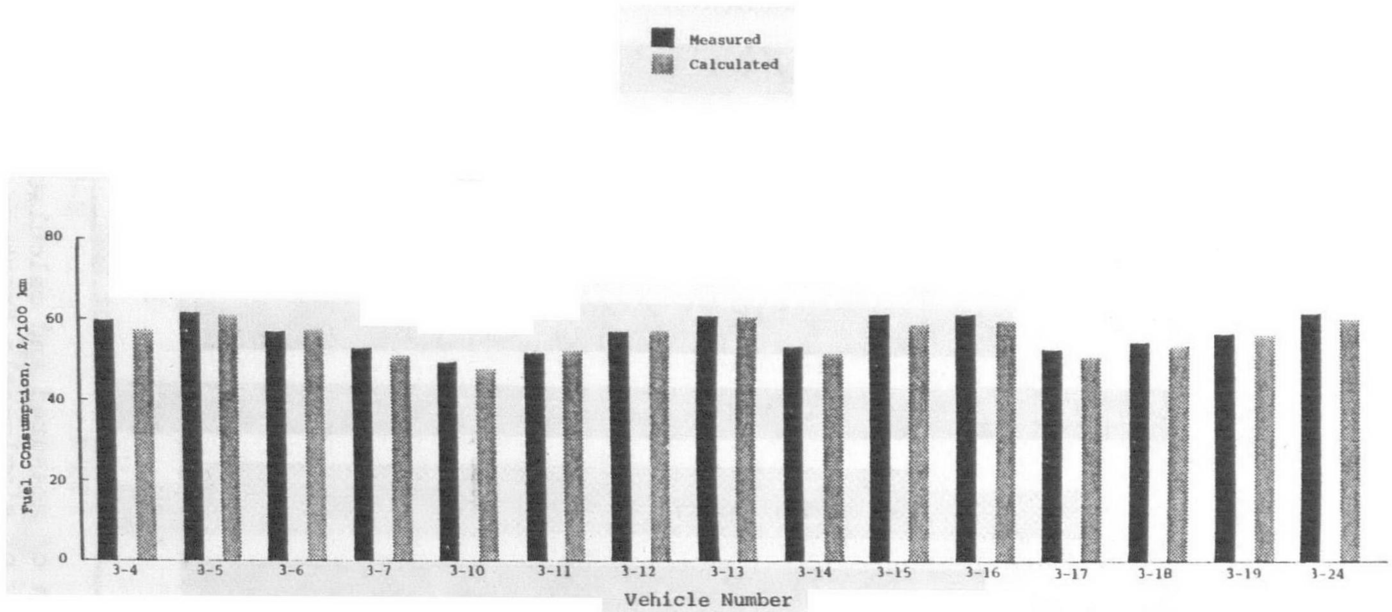


Figure 37. Comparison of measured and calculated fuel consumption of dual-axle tractors

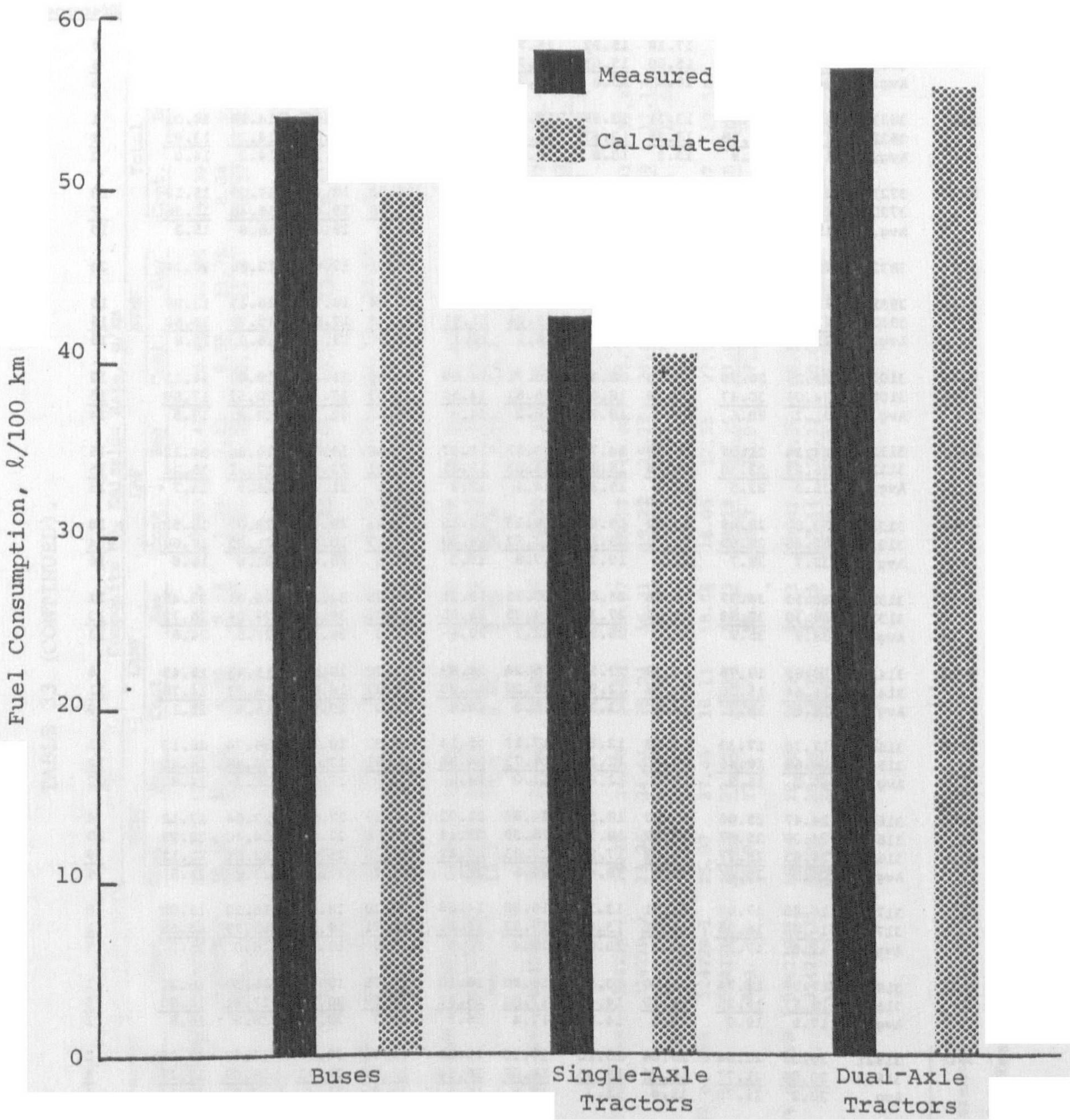


Figure 38. Comparison of measured and calculated fuel consumption of buses, single-axle tractors, and dual-axle tractors

TABLE 33. COMPARISON OF EMISSION RATES OF NO_x MEASURED CONTINUOUSLY AND MEASURED IN BAGS FOR SEVERAL VEHICLES TESTED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE

Vehicle Number	Test	Composite NO_x Emission Rate, g/km: NYNF Cont.	NYNF Bag	LANF Cont.	LANF Bag	LAF Cont.	LAF Bag	NYNF Cont.	NYNF Bag	Total Cont.	Total Bag	Total Percent Difference[a]
3-5	3521	24.13	23.03	17.18	15.92	15.74	14.62	26.24	24.60	17.83	16.64	7
	3522	23.91	22.83	15.60	15.63	14.71	14.01	21.09	20.13	16.59	15.79	5
	Avg.	24.0	22.9	16.8	15.8	15.2	14.3	23.7	22.4	17.2	16.2	6
3-6	3621	17.36	19.00	13.31	13.95	13.50	12.68	17.38	17.96	14.19	14.03	1
	3622	17.29	18.88	13.35	13.67	13.61	12.66	16.89	18.01	14.20	13.93	2
	Avg.	17.3	18.9	13.3	13.8	13.6	12.7	17.1	18.0	14.2	14.0	2
3-7	3721	20.02	20.88	14.90	14.35	16.60	14.08	22.53	18.43	17.09	15.13	13
	3722	18.07	19.44	13.62	13.36	16.75	14.83	19.78	19.48	16.48	15.36	7
	Avg.	19.0	20.2	14.3	13.9	16.7	14.4	21.2	19.0	16.8	15.2	10
3-8	3832	20.09	17.84	12.67	11.11	11.10	8.53	17.01	12.45	12.86	10.34	24
3-9	3931	23.27	20.54	15.40	13.57	14.28	12.36	21.94	18.37	16.13	13.99	15
	3932	23.32	20.97	15.00	13.19	13.94	11.91	21.46	17.87	15.79	13.62	16
	Avg.	23.3	20.8	15.2	13.4	14.1	12.1	21.7	18.1	16.0	13.8	16
3-10	31021	29.29	26.78	20.33	18.46	15.71	14.69	27.50	19.85	19.07	17.11	12
	31022	34.08	30.47	20.29	18.08	16.61	14.50	33.65	27.64	20.52	17.89	15
	Avg.	31.7	28.6	20.3	18.3	16.2	14.6	30.6	23.8	19.8	17.5	14
3-11	31121	24.34	21.57	16.89	14.73	13.57	11.87	23.68	19.76	16.24	14.12	15
	31122	26.23	23.38	18.44	15.83	14.63	12.61	25.31	22.68	17.51	15.24	15
	Avg.	25.3	22.5	17.7	15.3	14.1	12.2	24.5	21.2	16.9	14.7	15
3-12	31221	33.00	28.49	22.92	19.44	18.13	15.15	35.43	29.93	22.07	18.62	18
	31222	32.45	28.99	22.30	19.15	17.52	15.49	31.17	26.84	21.22	18.60	14
	Avg.	32.7	28.7	22.6	19.3	17.8	15.3	33.3	28.4	21.6	18.6	16
3-13	31321	38.53	34.37	28.66	25.67	20.96	19.21	39.25	34.14	26.01	23.45	11
	31322	39.30	35.93	31.32	27.36	24.35	21.55	43.35	38.08	29.06	25.73	13
	Avg.	38.9	35.2	30.0	26.5	22.7	20.4	41.3	36.1	27.5	24.6	12
3-14	31421	18.65	18.76	14.49	13.57	16.24	14.89	19.78	19.96	15.43	15.45	6
	31422	16.64	15.58	14.26	12.98	16.29	14.20	18.87	18.63	16.33	14.78	11
	Avg.	18.6	18.7	14.4	13.3	16.3	14.6	19.3	19.3	16.4	15.1	9
3-15	31521	17.76	17.39	13.93	12.58	17.17	15.14	19.37	18.46	16.74	15.13	11
	31522	16.68	16.45	13.37	12.11	16.73	14.54	18.51	17.11	16.48	14.45	12
	Avg.	17.2	16.9	13.6	12.4	17.0	14.8	18.9	17.8	16.2	14.8	12
3-16	31621	24.47	25.66	19.90	18.53	24.63	22.02	27.19	27.51	23.84	22.12	8
	31622	24.39	25.87	20.27	18.73	25.39	22.14	27.56	27.85	24.40	22.29	10
	31623	24.63	25.27	19.62	17.95	23.63	20.82	25.28	25.95	23.01	21.11	9
	Avg.	24.5	25.6	19.9	18.4	24.6	21.7	26.7	27.1	23.8	21.8	9
3-17	31721	16.85	17.47	14.61	13.54	16.20	14.66	19.29	18.59	16.20	15.02	8
	31722	14.83	16.95	13.71	13.69	16.53	15.61	16.71	19.48	15.79	15.66	1
	Avg.	15.8	17.2	14.2	13.6	16.4	15.1	18.0	19.0	16.0	15.3	5
3-18	31821	17.17	18.74	14.00	13.56	16.88	16.18	17.75	19.68	16.39	16.21	1
	31822	18.57	19.25	14.70	14.40	17.83	16.87	19.59	20.26	17.41	16.90	3
	Avg.	17.9	19.0	14.4	14.0	17.4	16.5	18.7	20.0	16.9	16.6	2
3-19	31921	20.32	21.54	15.44	15.10	17.50	16.39	19.54	20.90	17.50	17.00	3
	31922	20.08	21.77	16.08	15.45	18.09	16.54	20.84	21.93	18.09	17.27	5
	Avg	20.2	21.75	15.8	15.3	17.8	16.5	20.2	21.4	17.8	17.1	4
3-20	32031	11.92	15.46	9.18	10.19	9.28	8.55	9.35	14.27	9.51	10.07	-6
	32032	12.62	16.30	9.84	10.36	10.20	8.71	9.32	13.49	10.26	10.23	0
	Avg	12.3	15.9	9.51	10.3	9.74	8.63	9.34	13.9	9.89	10.2	-3
3-21	32131	18.53	19.15	12.60	12.43	9.00	8.48	17.16	18.57	11.49	11.34	1
	32132	18.27	18.21	12.85	12.14	9.06	7.77	17.91	17.59	11.61	10.65	9
	Avg	18.4	18.7	12.7	12.3	9.03	8.13	17.5	18.1	11.6	11.0	5
3-22	32231	24.24	24.96	16.68	15.98	17.23	15.17	20.87	22.43	18.14	16.98	7
	32232	26.21	24.57	17.84	16.28	16.75	15.10	24.17	23.07	18.60	17.03	9
	Avg	25.2	24.8	17.3	16.1	17.0	15.1	22.5	22.8	18.4	17.0	8

[a]Percent differences calculated relative to bag NO_x

TABLE 33 (CONTINUED).

Vehicle Number	Dynamometer Inertia	Test	Composite NO_x Emission Rate, g/km: NYNF Cont.	NYNF Bag	LANF Cont.	LANF Bag	LAF Cont.	LAF Bag	NYNF Cont.	NYNF Bag	Total Cont.	Total Bag	Total Percent Difference[a]
3-23	61% of GVW	32325R-1	10.53	11.81	8.11	8.19	7.80	7.41	10.60	12.05	8.39	8.42	0
		32325R-2	10.68	12.61	8.01	8.34	7.84	7.11	9.98	11.75	8.34	8.32	0
		Avg.	10.6	12.2	8.06	8.27	7.82	7.26	10.3	11.9	8.37	8.37	0
	70% of GVW	32322	10.02	13.17	7.67	9.01	8.42	8.11	11.01	13.29	8.65	9.25	-6
		32324	11.39	12.41	8.50	8.66	8.46	7.60	10.77	12.47	8.96	8.73	3
		Avg.	10.7	12.8	8.09	8.84	8.44	7.86	10.9	12.9	8.81	8.99	-2
	80% of GVW	32327R-1	12.65	b	9.18	9.26	9.36	7.78	11.73	12.93	9.86	b	b
		32327R-2	14.54	14.54	9.91	9.83	10.24	9.35	13.43	14.66	10.87	10.43	4
		Avg.	13.6	14.5[c]	9.55	9.55	9.80	8.57	12.6	13.8	10.4	10.4[c]	b
	93% of GVW	32326R-1	13.88	14.89	10.30	10.20	10.98	10.20	13.80	14.79	11.38	11.09	3
		32326R-2	12.74	14.16	9.41	9.72	10.25	9.78	12.95	14.24	10.57	10.61	0
		Avg.	13.3	14.5	9.86	9.96	10.6	9.99	13.4	14.5	11.0	10.8	2
3-24	55% of GVW	32424R-1	21.38	21.91	14.28	14.38	12.90	12.39	21.23	21.44	14.72	14.49	2
		32424R-3	21.82	22.16	14.53	13.99	12.65	12.33	21.14	20.31	14.83	14.31	4
		Avg.	21.6	22.0	14.4	14.2	12.8	12.4	21.2	20.9	14.8	14.4	3
	70% of GVW	32421R-1	24.29	24.78	17.14	17.17	16.27	16.00	25.77	26.35	18.03	17.97	0
		32421R-2	23.36	24.61	15.94	16.31	15.22	15.17	24.01	24.76	16.89	17.12	-1
		Avg.	23.8	24.7	16.5	16.7	15.8	15.6	24.9	25.6	17.5	17.6	-1
	86% of GVW	32422R-1	25.97	27.43	18.11	18.54	18.05	17.55	27.00	27.59	19.57	19.54	0
		32422R-3	26.11	27.11	19.23	18.83	19.28	18.15	27.94	28.20	20.65	19.99	3
		Avg.	26.0	27.3	18.7	18.7	18.7	17.9	27.5	27.9	20.1	19.8	2
	97% of GVW	32423R-1	28.02	28.30	20.35	19.73	20.42	19.35	28.55	28.06	21.84	21.04	4
		32423R-3	30.96	29.99	21.20	20.25	22.14	20.32	30.09	29.18	23.44	21.97	6
		Avg.	29.5	29.2	20.8	20.0	21.3	19.8	29.3	28.6	22.6	21.5	5

[a] Percent differences calculated relative to bag NO_x

[b] *No data*

[c] Average is from Test 32327 Run 2 only

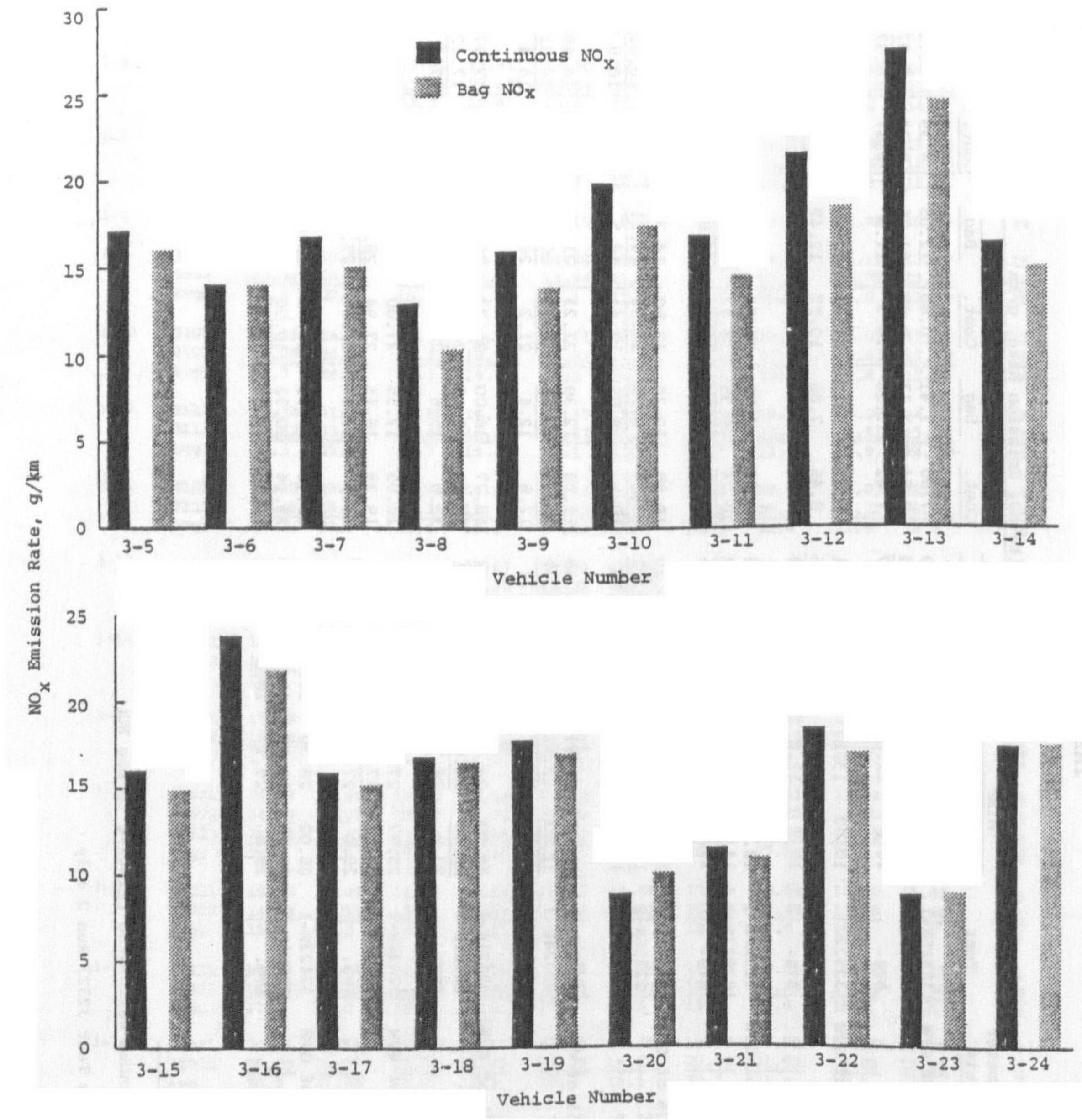


Figure 39. Comparison of continuously measured and bag NO_x for Task 3 vehicles

TABLE 34. COMPARISON OF ALDEHYDE AND KETONE EMISSION RATES FROM VEHICLES TESTED OVER ONE COLD-START AND THREE HOT-STARTS OF THE CHASSIS VERSION OF THE TRANSIENT CYCLE

	Emission Rate, mg/km Single-Axle Tractors			
Vehicle No.	3-1	3-2	3-3	3-23[d,e]
Vehicle Description	Cummins Form. 350	IHC DT-466	Cummins Form. 290	Cummins NTC-300
Formaldehyde	10(100%)[f]	13(100%)	22(76%)	151(33%)
Acetaldehyde	ND[a]	ND	3	122
Acrolein	ND	ND	ND	46
Propionaldehyde	ND	ND	ND	21
Acetone	b	b	b	43
Crotonaldehyde	ND	ND	ND	13
Isobutyraldehyde	ND	ND	ND	} 30
Methylethylketone	ND	ND	ND	}
Benzaldehyde	ND	ND	4	13
Hexanaldehyde	ND	ND	ND	12
Total	10	13	29	451

	Buses				
Vehicle No.	3-8[c]	3-9[c]	3-20[d]	3-21[d]	3-22[d]
Vehicle Description	DD 6V-71N	DD6V-71N	DD 6V-71N	Cat 3208	DD 8V-71N
Formaldehyde	172(59%)	123(41%)	250(48%)	123(36%)	138(31%)
Acetaldehyde	121	113	184	119	168
Acrolein	ND	ND	26	13	29
Propionaldehyde	ND	ND	12	ND	20
Acetone	ND	36	36	41	42
Crotonaldehyde	ND	ND	5	9	12
Isobutyraldehyde	ND	ND	4	} 18	15
Methylethylketone	ND	ND		}	
Benzaldehyde	ND	ND	3	10	15
Hexanaldehyde	ND	30	ND	10	9
Total	293	302	520	343	448

[a]Not detected above the minimum detection value (MDV)
[b]Background interference prevented accurate acetone measurement.
[c]Analyzed by means of the improved 2,4-dinitrophenylhydrazine (DNPH) method
[d]Analyzed with the improved DNPH procedure that was modified to improve the detection limits
[e]Vehicle 3-23 was operated at 80 percent of standard horsepower
[f]Fraction of total aldehydes and ketones that is formaldehyde

TABLE 34 (CONTINUED)

	Emission Rate, mg/km Dual Axle Tractors				
Vehicle No.	3-4	3-5	3-6	3-7	3-10[c]
Vehicle Description	DD 8V-92TA	DD 8V-92TA	Cummins NTC-400	Cummins Form. 350	Mack EM6-285R
Formaldehyde	36 (68%)	51 (88%)	118 (78%)	18 (45%)	79 (42%)
Acetaldehyde	9	2	10	ND	81
Acrolein	ND[a]	ND	ND	ND	ND
Propionaldehyde	3	ND	3	3	ND
Acetone	b	b	b	b	28
Crotonaldehyde	ND	ND	ND	ND	ND
Isobutyraldehyde	ND	ND	ND	ND	ND
Methylethylketone	ND	ND	ND	ND	ND
Benzaldehyde	5	5	8	3	ND
Hexanaldehyde	ND	ND	12	16	ND
Total	53	58	151	40	188

Vehicle No.	3-11[c]	3-12[c]	3-13[c]	3-14[d]	3-15[d]
Vehicle Description	Mack EM 6-285	Cat 3406 Economy	Cat 3406	Cummins Form. 350	Cummins Form. 350
Formaldehyde	33 (39%)	75 (49%)	80 (34%)	129 (26%)	107 (56%)
Acetaldehyde	51	57	116	203	ND
Acrolein	ND	ND	ND	ND	ND
Propionaldehyde	ND	ND	ND	18	15
Acetone	ND	21	17	87	48
Crotonaldehyde	ND	ND	ND	9	6
Isobutyraldehyde	ND	ND	ND	} 24	16
Methylethylketone	ND	ND	ND		
Benzaldehyde	ND	ND	ND	12	ND
Hexanaldehyde	ND	ND	25	12	ND
Total	84	153	238	494	192

Vehicle No.	3-16[d]	3-17[d]	3-18[d]	3-19[d]	3-24[d]
Vehicle Descirption	Cummins NTC-290	Cummins Form. 350	Cummins NTC-300	Cummins NTC-300	DD8V-92TA
Formaldehyde	8 (5%)	131 (29%)	71 (37%)	56 (35%	96 (33%)
Acetaldehyde	98	188	71	56	124
Acrolein	9	15	8	11	17
Propionaldehyde	16	16	ND	7	9
Acetone	35	51	25	18	16
Crotonaldehyde	5	10	4	5	4
Isobutyraldehyde Methylethylketone }	5	16	8	5	10
Benzaldehyde	ND	9	4	2	7
Hexanaldehyde	ND	10	2	2	10
Total	175	446	193	162	293

An improved version of the 2,4-dinitrophenylhydrazine method for aldehyde and ketone analyses was used to analyze samples from Vehicles 3-8 through 3-24. When used with a more sensitive detector, this procedure has lower detection limits than the original method. The total emission rates of aldehydes and ketones calculated for Table 34 reflect the improved detection limits of the new procedure.

In general, the formaldehyde, acetaldehyde, and total aldehyde and ketone emission rates were higher for buses than for single-axle and dual-axle tractors. Overall, dual-axle tractors produced higher aldehyde and ketone emission rates than single-axle tractors, but large variations in the rates occurred with both tractor types.

The formaldehyde fraction of the total aldehyde and ketone emission rate was calculated and is shown in parentheses in Table 34. The ratio of formaldehyde emission rate to total aldehyde and ketone emission rate was relatively high for the first seven vehicles (possibly due to the use of a different variation of the DNPH procedure for those vehicles) so the data for the first seven vehicles were not used in the following comparisons. The percentage of formaldehyde from dual-axle tractors ranged from 26 to 56 (excluding the 5 percent for Vehicle 3-16) and from 31 to 59 percent for buses. Formaldehyde made up 33 percent of total aldehydes and ketones for Vehicle 3-23. This was the only single-axle tractor tested using the improved DNPH method.

Only one vehicle, Vehicle 3-17, produced phenols above the minimum detection limits of the phenols procedure. Of the eleven phenols measurable by the procedure, only 2,3,5-trimethylphenol was detected. The measured rate was 6.9 mg/km, with a detection limit of 2 mg/km.

The odor of vehicle exhaust was measured using a Diesel Odor Analysis System (DOAS). With this method, exhaust odor is measured as two components; LCA, which includes aromatics, and LCO, which are oxygenated compounds. The results of odor analysis are listed in Table 35 by vehicle type. Most vehicles produced higher levels of LCA than LCO for all vehicle types. As a group, buses emitted higher levels of LCA and lower LCO levels than single-axle or dual-axle tractors. Dual-axle tractors generally produced greater amounts of LCA and LCO than single-axle tractors.

Particulate was sampled on 47 mm Pallflex filters and on 20 X 20 inch Pallflex filters for Task 3 vehicles. The particulate collected on 47 mm filters was analyzed for metals and several other elements at EPA-RTP. A listing of the available elemental emission rates in mg/km are given in Table 36. In Table 37 the elements which were not consistently detected have been deleted to allow a better comparison of the remaining elements. Phosphorus and sulfur were emitted at levels above the minimum detection values (MDV) with all vehicles tested in Task 3, and magnesium, chlorine, and potassium were detected at measurable levels with several of the vehicles tested.

Buses produced lower levels of sulfur and potassium than single-axle or dual-axle tractors while dual-axle tractors emitted more sulfur than did single-axle tractors. Relative to the other vehicles tested, city bus 3-20 produced higher levels of phosphorus and iron and Vehicle 3-6 produced higher levels of sulfur and iron.

Particulate collected on 20 X 20 inch filters was extracted to determine the fraction of organic solubles on the filter. The extracts were analyzed for nitropyrenes and mutagenic activity. Results of nitropyrene analysis are shown in Table 38. 1-Nitropyrene and three dinitropyrenes (1,3-; 1,6-; and 1,8-dinitropyrenes) were measured

TABLE 35. COMPARISON OF DOAS ODOR EMISSION RATES FROM VEHICLES TESTED OVER ONE COLD-START AND THREE HOT-STARTS OF THE CHASSIS VERSION OF THE TRANSIENT CYCLE

Vehicle			Emission Rate, mg/km LCA	LCO
Single-Axle Tractor				
3-1	Cummins Form. 350		96	60
3-2	IHC DT-466		254	45
3-3	Cummins Form. 290		132	131
3-23	Cummins NTC-300		531	284
		Avg.	253	130
Bus				
3-8	Bus DD 6V-71N		1376	132
3-9	Bus DD 6V-71N		1034	169
3-20	Bus DD 6V-71N		784	108
3-21	Bus Cat 3208		321	56
3-22	Bus DD 8V-71N		959	42
		Avg.	895	101
Dual-Axle Tractor				
3-4	DD 8V-92TA		330	225
3-5	DD 8V-92TA		449	89
3-6	Cummins NTC-400		529	120
3-7	Cummins Form. 350		[a]	[a]
3-10	Mack EM6-285R		258	237
3-11	Mack EM6-285		211	136
3-12	Cat. 3406 Economy		365	234
3-13	Cat. 3406		190	11
3-14	Cummins Form. 350		343	755
3-15	Cummins Form. 350		441	221
3-16	Cummins NTC-290		210	194
3-17	Cummins Form. 350		498	244
3-18	Cummins NTC-300		310	85
3-19	Cummins NTC-300		353	304
3-24	DD 8V-92TA		266	74
		Avg.	340	204

[a] Sample contaminated, no valid data

TABLE 36. COMPARISON OF ELEMENTAL EMISSION RATES (IN MG/KM) FROM VEHICLES OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE

	Single-Axle Tractors				Buses				
Element	3-1 Cummins NTC 350	3-2 IHC DT-466	3-3 Cummins Form. 290	3-23 Cummins NTC-300	3-8 City Bus DD6V-71N	3-9 City Bus DD6V-71N	3-20 City Bus DD 6V-71N	3-21 City Bus Cat 3208	3-22 City Bus DD 8V-71N
Magnesium	ND[a]	ND	1.5[b]	ND	ND	ND	3.6	ND	1.4
Phosphorus	0.9	0.6	1.6	1.3	2.1	1.8	7.3	1.1	1.4
Sulfur	19.0	15.5	21.1	26.7	7.6	8.0	15.3	5.0	9.8
Chlorine	ND	ND	0.4[b]	ND	0.6	0.5[b]	0.5	0.1[b]	0.2[b]
Potassium	ND	ND	35.8	ND	6.8[b]	13.7	ND	ND	ND
Calcium	ND	ND	ND	ND	ND	ND	ND	ND	ND
Titanium	ND	0.1[b]	ND	0.7	ND	ND	ND	ND	ND
Vanadium	ND	ND	ND	ND	ND	ND	ND	ND	ND
Manganese	ND	ND	ND	ND	1.7[b]	0.7[b]	15.3	ND	ND
Iron	2.8	0.9[b]	1.8[b]	3.2	4.3	ND	23.8	ND	ND
Bromine	ND	ND	ND	ND	ND	ND	ND	0.52[b]	ND
Zinc	ND	ND	ND	115.0	167.1[b]	167.3[b]	ND	ND	ND
Selenium	ND	ND	ND	ND	0.6[b]	ND	ND	ND	ND
Strontium	ND	1.9[b]	ND	15.5	8.7	8.1	ND	ND	ND
Molybdenum	ND	ND	ND	ND	5.6[b]	5.2[b]	ND	ND	ND
Tin	ND	ND	ND	ND	ND	ND	2.56	0.33[b]	ND
Barium	ND	ND	63.9[b]	ND	64.2[b]	74.0[b]	ND	ND	ND
Wolfram	ND	ND	ND	ND	2.8[b]	ND	ND	ND	ND

[a] Not detected, levels below emission rate of 0.1 mg/km
[b] Detected at the detection limit

TABLE 36. (CONTINUED)

Element	3-4 DD 8V-92TA	3-5 DD 8V-92TA	3-6 Cummins NTC-400	3-7 Cummins Form. 350	3-10 Mack EM6-285R	3-11 Mack EM6-285	3-12 Cat 3406 Economy	3-13 Cat 3406	3-14 Cummins Form. 350	3-15 Cummins Form. 350	3-16 Cummins NTC-290	3-17 Cummins Form. 350	3-18 Cummins NTC-300	3-19 Cummins NTC-300	3-24 DD 8V-92TA
	Dual-Axle Tractors														
Magnesium	3.7	3.5	ND[a]	ND	ND	ND	ND	ND	ND	ND	ND	7.0	7.8	7.4	ND
Phosphorus	1.5	1.6	2.4	0.5	1.4	1.4	6.4	0.9	0.4	2.2	2.0	1.1	0.4	1.5	1.3
Sulfur	20.8	21.4	43.8	22.7	23.5	29.2	32.9	23.9	22.7	30.2	36.3	27.7	23.2	29.2	26.7
Chlorine	0.5	0.6	0.3[b]	ND	ND	ND	ND	0.2[b]	ND	ND	ND	0.6	0.7	0.8	ND
Potassium	50.2	42.0	ND	ND	16.4	10.9	9.5[b]	ND	5.8[b]	ND	ND	22.2[b]	26.8[b]	28.4[b]	ND
Calcium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	54.4	53.8	60.7	ND
Titanium	ND	ND	ND	ND	ND	ND	ND	ND	0.5[b]	ND	ND	ND	ND	ND	0.4
Vanadium	ND	ND	ND	ND	0.3[b]	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Manganese	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Iron	ND	ND	11.6	ND	ND	2.4	4.5	1.9[b]	2.3[b]	3.2	4.2	ND	ND	1.0	0.6
Bromine	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Zinc	ND	ND	ND	ND	139.0[b]	138.1[b]	139.6[b]	ND	86.6[b]	ND	ND	ND	ND	ND	ND
Selenium	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Strontium	ND	ND	ND	ND	7.3	7.2	6.9	ND	5.5[b]	ND	ND	ND	ND	ND	1.4
Molybdenum	ND	ND	ND	ND	4.2[b]	3.9[b]	4.7[b]	ND	3.4[b]	ND	ND	ND	ND	ND	ND
Tin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Barium	87.4	68.0[b]	ND	ND	72.8	60.7[b]	57.6[b]	ND	35.6[b]	ND	ND	ND	ND	ND	ND
Wolfram	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

[a]Not detected, levels below emission rate of 0.1 mg/km
[b]Detected at the detection limit

TABLE 37. SUMMARY OF MOST PREVALENT ELEMENTAL EMISSIONS (IN MG/KM) FROM VEHICLES OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE

	Single Axle Tractors				Buses				
Element	3-1 Cummins NTC-350	3-2 IHC DT-466	3-3 Cummins Form. 290	3-23 Cummins NTC-300	3-8 City Bus DD6V-71N	3-9 City Bus DD6V-71N	3-20 City Bus DD 6V-71N	3-21 City Bus Cat 3208	3-22 City Bus DD 8V-71N
Magnesium	ND[a]	ND	1.5[b]	ND	ND	ND	3.6	ND	1.4
Phosphorus	0.9	0.6	1.6	0.9	2.1	1.8	7.3	1.1	2.2
Sulfur	19.0	15.5	21.1	19.6	7.6	8.0	15.3	5.0	9.8
Chlorine	ND	ND	0.4[b]	ND	0.6	0.5[b]	0.5	0.1[b]	0.2[b]
Potassium	ND	ND	35.8	ND	6.8[b]	13.7	ND	ND	ND
Iron	2.8	0.9[b]	1.8[b]	3.2	4.3	ND	23.8	ND	ND
Zinc	ND	ND	ND	155.0	167.1[b]	167.3[b]	ND	ND	ND
Strontium	ND	1.9[b]	ND	15.5	8.7	8.1	ND	ND	ND
Molybdenum	ND	ND	ND	ND	5.6[b]	5.2[b]	ND	ND	ND
Barium	ND	ND	63.9[b]	ND	64.2[b]	74.0[b]	ND	ND	ND

	Dual Axle Tractors														
Element	3-4 DD 8V-92TA	3-5 DD 8V-92TA	3-6 Cummins NTC-400	3-7 Cummins Form. 350	3-10 Mack EM6-285R	3-11 Mack EM6-285	3-12 Cat 3406 Economy	3-13 Cat 3406	3-14 Cummins Form. 350	3-15 Cummins Form. 350	3-16 Cummins NTC-290	3-17 Cummins Form. 350	3-18 Cummins NTC-300	3-19 Cummins NTC-300	3-24 DD 8V-92TA
Magnesium	3.7	3.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.0	7.8	7.4	ND
Phosphorus	1.5	1.6	2.4	0.5	1.4	1.4	6.4	0.9	0.4	2.2	2.0	1.1	0.4	1.5	1.3
Sulfur	20.8	21.4	43.8	22.7	23.5	29.2	32.9	23.9	22.7	30.2	36.3	27.7	23.2	29.2	26.7
Chlorine	0.5	0.6	0.3[b]	ND	ND	ND	ND	0.2[b]	ND	ND	ND	0.6	0.7	0.8	ND
Potassium	50.2	42.0	ND	ND	16.4	10.9	9.5[b]	ND	5.8[b]	ND	ND	22.2[b]	26.8[b]	28.4[b]	ND
Iron	ND	ND	11.6	ND	ND	2.4	4.5	1.9[b]	2.3[b]	3.2	4.2	ND	ND	1.0	0.6
Zinc	ND	ND	ND	ND	139.0[b]	138.1[b]	139.6[b]	ND	86.6[b]	ND	ND	ND	ND	ND	ND
Strontium	ND	ND	ND	ND	7.3	7.2	6.9	ND	5.5[b]	ND	ND	ND	ND	ND	1.4
Molybdenum	ND	ND	ND	ND	4.2[b]	3.9[b]	4.7[b]	ND	3.4[b]	ND	ND	ND	ND	ND	ND
Barium	87.4	68.0[b]	ND	ND	72.8	60.7[b]	57.6[b]	ND	35.6[b]	ND	ND	ND	ND	ND	ND

[a]Not detected, levels below emisison rate of 0.1 mg/km
[b]Detected at the detection limit

TABLE 38. COMPARISON OF NITROPYRENE EMISSION RATES (IN ORGANIC EXTRACTABLES) FROM VEHICLES TESTED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE

Vehicle No.	Vehicle Description	Emission Rate, μg/km 1-Nitropyrene	1,3-Dinitropyrene	1,6-Dinitropyrene	1,8-Dinitropyrene
		Single-Axle Tractors			
3-1	Cummins Formula 350	9	ND[d]	ND	[a]
3-2	IHC DT-466B	1	ND	ND	[a]
3-3	Cummins Formula 290	9	ND	ND	[a]
3-23	Cummins NTC-300	2	ND	ND	ND
	Avg.	5			
		Buses			
3-8	Bus DD 6V-71N	ND	ND	ND	ND
3-9	Bus DD 6V-71N	ND	ND	ND	ND
3-20	Bus DD 6V-71N	ND	ND	ND	ND
3-21	Bus Cat 3208	1	ND	ND	ND
3-22	Bus DD 8V-71N	ND	ND	ND	ND
	Avg.	ND			
		Dual-Axle Tractors			
3-4	DD 8V-92TA	6	ND	ND	[a]
3-5	DD 8V-92TA	8	ND	ND	ND
3-6	Cummins NTC-400	1	ND	ND	ND
3-7	Cummins Formula 350	2	ND	ND	ND
3-10	Mack EM6-285R	1	ND	ND	ND
3-11	Mack EM6-285	2	ND	ND	ND
3-12	Cat 3406 Economy	3	ND	ND	ND
3-13	Cat 3406	17	ND	ND	ND
3-14	Cummins Formula 350	1	ND	ND	ND
3-15	Cummins Formula 350	1	ND	ND	ND
3-16	Cummins NTC-290	2	ND	ND	ND
3-17	Cummins Formula 350	1	ND	ND	ND
3-18	Cummins NTC-300	1	ND	ND	ND
3-19	Cummins NTC-300	1	ND	ND	ND
3-24	Detroit Diesel 8V-92TA	4	ND	ND	ND
	Avg.	8			

[a] 1,8-Dinitropyrene eluted at same retention time as 1-Nitropyrene values reported as 1-Nitropyrene

[b] Not detected, levels were at or below the emission rate of 1 μg/km

in the extract samples. None of the dinitropyrenes were found at levels above 1 microgram/km. 1-Nitropyrene was produced at levels from 1 to 17 micrograms/km. Of the three vehicle types tested, buses produced the lowest levels of 1-nitropyrene. Only bus 3-21 emitted detectable amounts of 1-nitropyrene. Single-axle tractors produced an average of 5 micrograms/km of 1-nitropyrene and dual-axle tractors produced an average of 4 micrograms/km. Eighteen of the twenty four vehicles tested emitted 3 micrograms/km, or less, of 1-nitropyrene.

An organic extract sample from each vehicle was analyzed for mutagenic activity using the Ames bioassay. The samples were analyzed in three tester strains, (TA1538, TA98 and TA100) in triplicate, with and without metabolic activation. The results expressed in revertants per microgram of extract, and in revertants per kilometer, are given in Table 39. Particulate emission rate, organic extractables, and soluble organic fraction are also listed in the table.

As a group, buses produced a lower Ames response than dual-axle tractors, which in turn produced lower Ames response than single-axle tractors. In general, the highest Ames activity for the three vehicle types occurred in tester strain TA100 without S9. Ames response in the presence of S9 did not vary significantly between the three tester strains for any of the vehicle types. An exception occurred among buses in tester strain TA100 for which the average Ames activity was more than double that of the other two tester strains.

Bar graphs of Ames activity (in rev/km) for individual Task 3 vehicles are shown for tester strains TA1538, TA98, and TA100 in Figures 40 through 42. Several of the vehicles gave consistently higher Ames responses in all tester strains. These were Vehicle 3-1 (single-axle tractor) and Vehicles 3-5, 3-6, and 3-13 (dual-axle tractors). Two buses produced relatively low Ames activity, Vehicles 3-8 and 3-20.

TABLE 39. SUMMARY OF AMES BIOASSAY ANALYSES FROM VEHICLES TESTED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE

				TA 1538				TA 98				TA 100			
				-S9		+S9		-S9		+S9		-S9		+S9	
Vehicle	Part Rate, g/km	SOF[a]	Extract Rate, g/km	rev/μg[b]	rev/km[c]	rev/μg	rev/km[c]	rev/μg	rev/km[c]	rev/μg	rev/km[c]	rev/μg	rev/km[c]	rev/μg	rev/km[c]
Single Axle Tractors															
3-1	1.16	0.354	0.41	0.88	361.2	1.34	550.1	1.31	537.7	1.47	603.4	1.42	582.9	0.88	361.2
3-2	0.81	0.288	0.23	0.20	46.6	0.83	193.3	0.85	197.9	1.07	249.2	2.56	596.1	0.93	216.6
3-3	1.44	0.340	0.49	0.56	274.2	1.20	587.5	0.81	396.6	0.98	479.8	0.64	313.3	0.76	372.1
3-23	1.19	0.473	0.56	0.27	152.0	0.76	427.8	0.54	304.0	0.75	422.2	1.33	748.6	1.25	703.6
Avg.	1.15	0.36	0.42		208		440		359		438		560		414
Buses															
3-8	4.42	0.069	0.30	0.07	21.2	0.17	51.6	0.07	21.2	0.13	39.4	0.24	72.8	0.20	60.6
3-9	1.44	0.307	0.44	0.14	61.8	0.43	189.8	0.21	92.7	0.36	158.9	0.49	216.3	0.50	220.7
3-20	3.61	0.096	0.35	0.05	17.3	0.15	52.0	0.10	34.7	0.16	55.4	0.16	55.4	0.32	110.9
3-21	0.96	0.390	0.37	0.16	59.9	0.41	153.5	0.20	74.9	0.53	198.4	0.62	232.1	1.02	381.9
3-22	1.54	0.487	0.75	0.10	75.0	0.25	187.5	0.12	90.0	0.25	187.5	0.54	405.0	0.87	652.5
Avg.	2.39	0.27	0.44		47		127		63		128		196		285
Dual Axle Tractors															
3-4	1.26	0.535	0.67	0.39	263.7	0.69	466.6	0.66	446.3	0.45	304.3	0.42	284.0	0.62	419.3
3-5	1.18	0.513	0.60	1.04	631.3	0.80	485.6	1.58	959.1	0.87	528.1	1.21	734.5	1.00	607.0
3-6	1.88	0.128	0.24	2.29	551.4	1.06	255.2	2.51	604.3	1.34	322.6	5.82	1401.3	1.76	423.8
3-7	1.16	0.148	0.17	1.45	248.6	1.63	279.5	1.67	286.3	1.22	209.2	4.07	697.9	1.55	265.8
3-10	1.47	0.124	0.18	0.52	94.7	0.71	129.3	0.77	140.2	0.75	136.6	1.33	242.2	1.84	335.0
3-11	1.80	0.069	0.12	0.80	99.7	1.03	128.4	1.04	129.6	1.19	148.3	1.76	219.3	2.12	264.2
3-12	2.85	0.159	0.45	0.21	95.0	0.36	162.8	0.73	330.2	0.68	307.6	0.83	375.4	0.71	321.2
3-13	1.59	0.166	0.26	2.06	543.7	1.29	340.5	1.71	451.3	1.82	480.4	2.43	641.4	2.30	607.1
3-14	1.25	0.129	0.16	0.57	91.8	1.34	215.8	1.39	223.9	1.12	180.4	0.79	127.2	1.19	191.7
3-15	2.59	0.192	0.50	0.38	189.0	0.63	313.3	0.58	288.4	0.71	353.1	1.00	497.3	0.59	293.4
3-16	1.33	0.155	0.21	1.25	257.7	1.51	311.3	1.47	303.0	1.83	377.2	0.88	181.4	1.34	276.2
3-17	1.32	0.201	0.26	1.32	350.2	1.28	339.6	1.10	291.8	1.44	382.1	1.06	281.2	1.08	286.6
3-18	0.85	0.208	0.18	1.57	277.6	1.42	251.1	1.33	235.1	1.70	300.6	1.59	281.1	1.39	245.8
3-19	1.32	0.156	0.21	0.58	119.4	1.24	255.3	1.06	218.3	1.42	292.4	1.27	261.5	1.21	249.2
3-24	1.35	0.411	0.55	0.22	122.1	0.40	221.9	0.48	266.3	0.42	233.0	0.52	288.5	0.64	355.1
Avg.	1.55	0.22	0.32		262		277		345		304		434		343

[a] soluble organic fraction
[b] rev/μg - revertants/μg extract
[c] rev/km have been divided by 1000

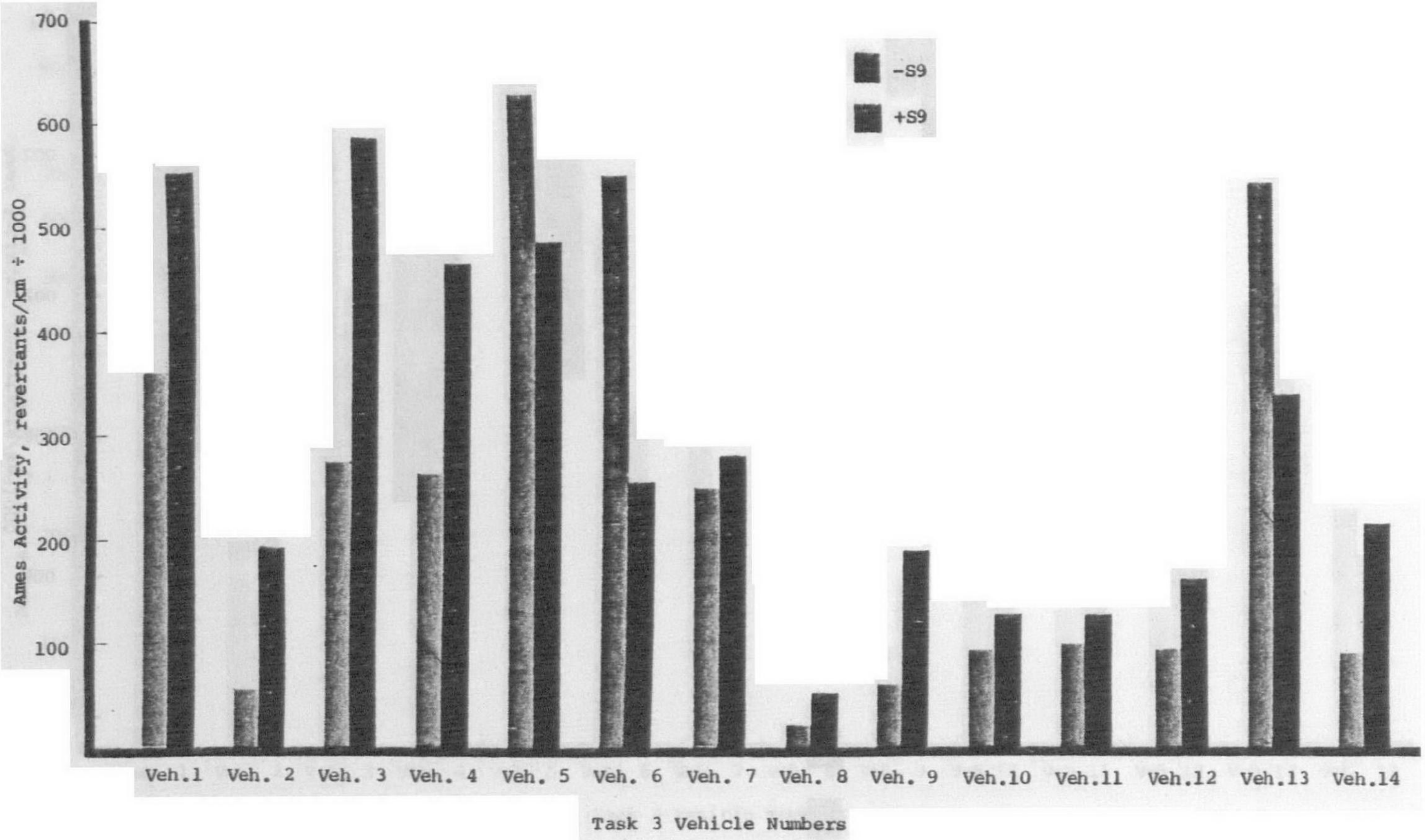


Figure 40. Comparison of TA1538 relative Ames activity

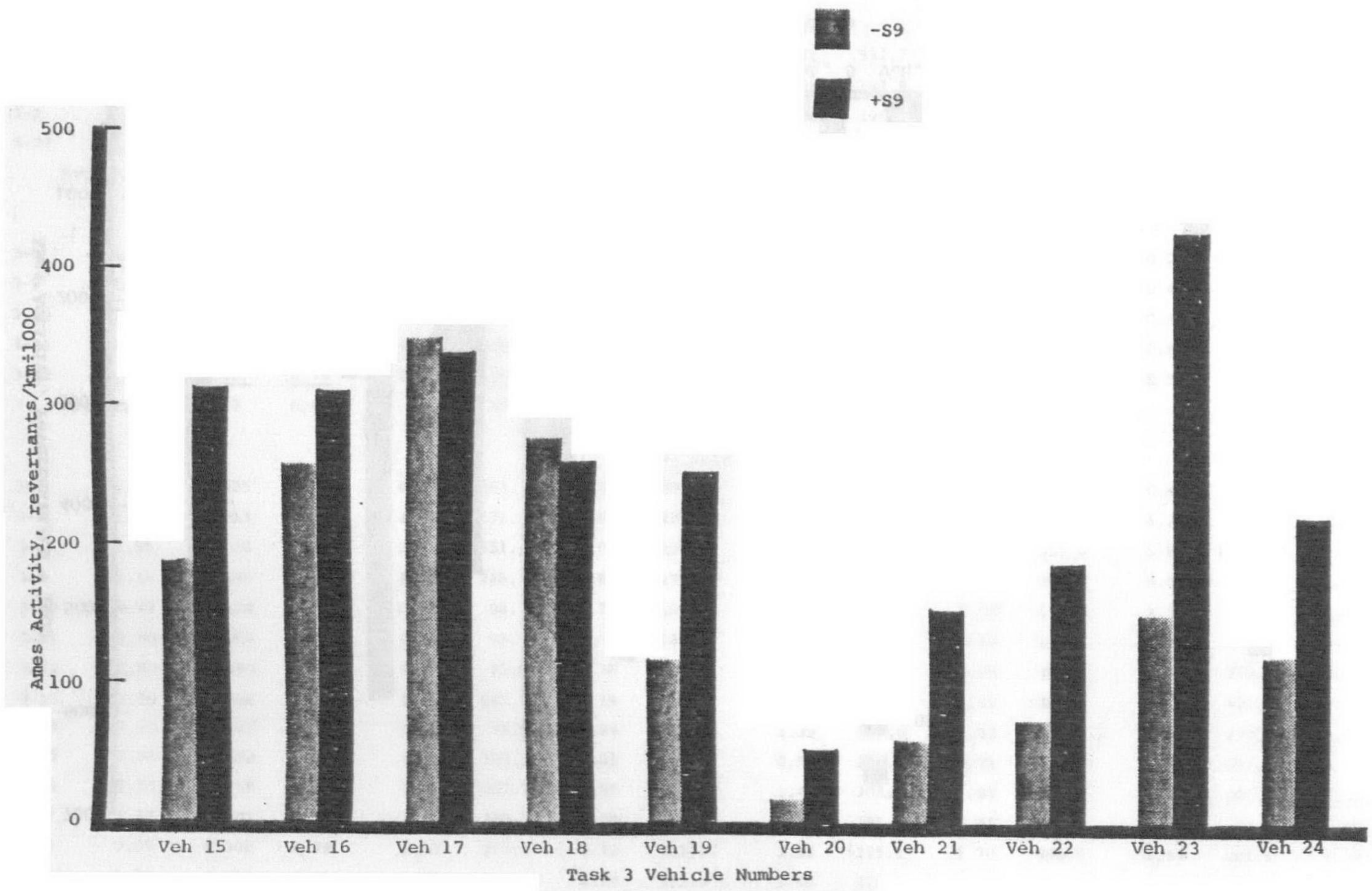


Figure 40 (Continued).

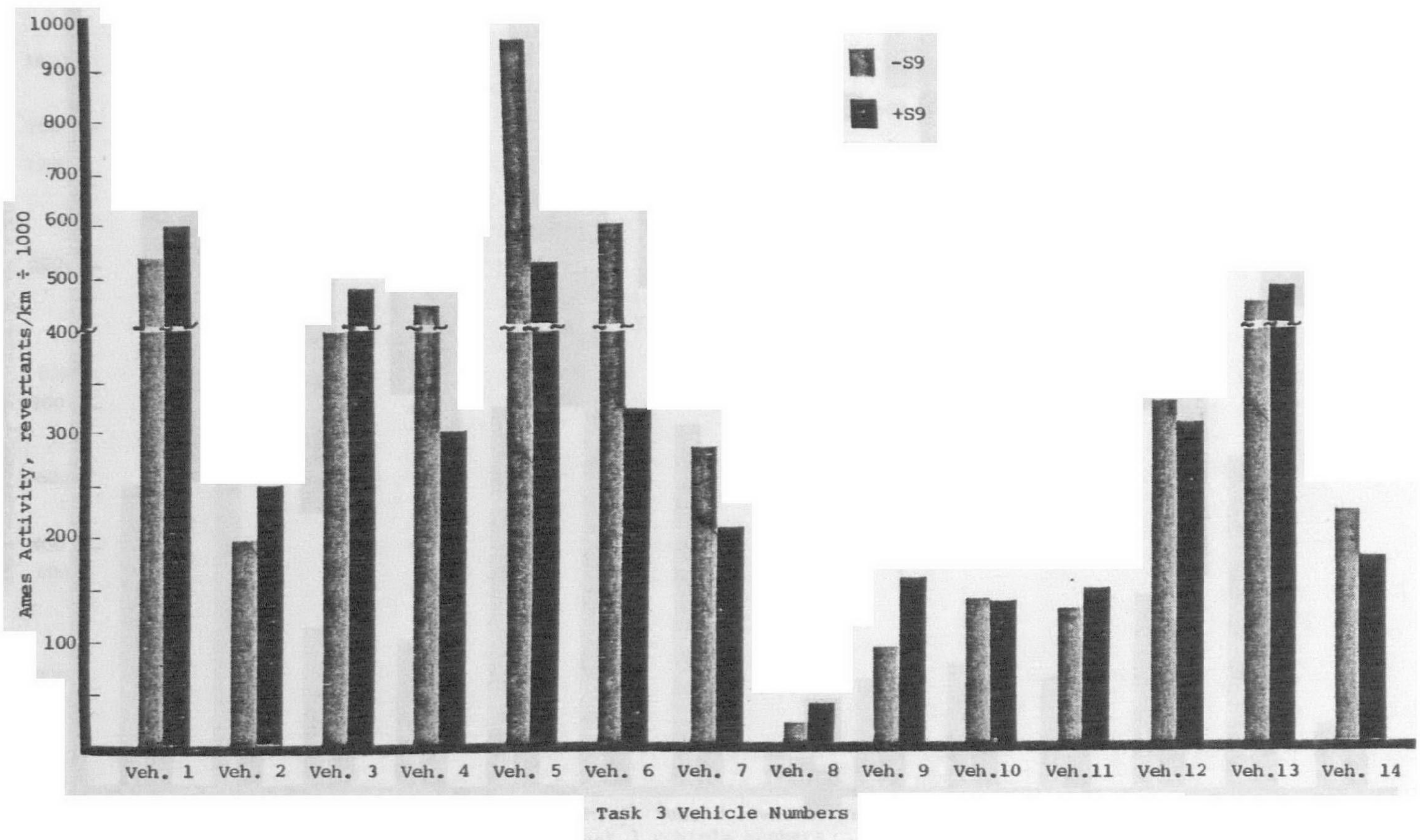


Figure 41. Comparison of TA98 relative Ames Activity

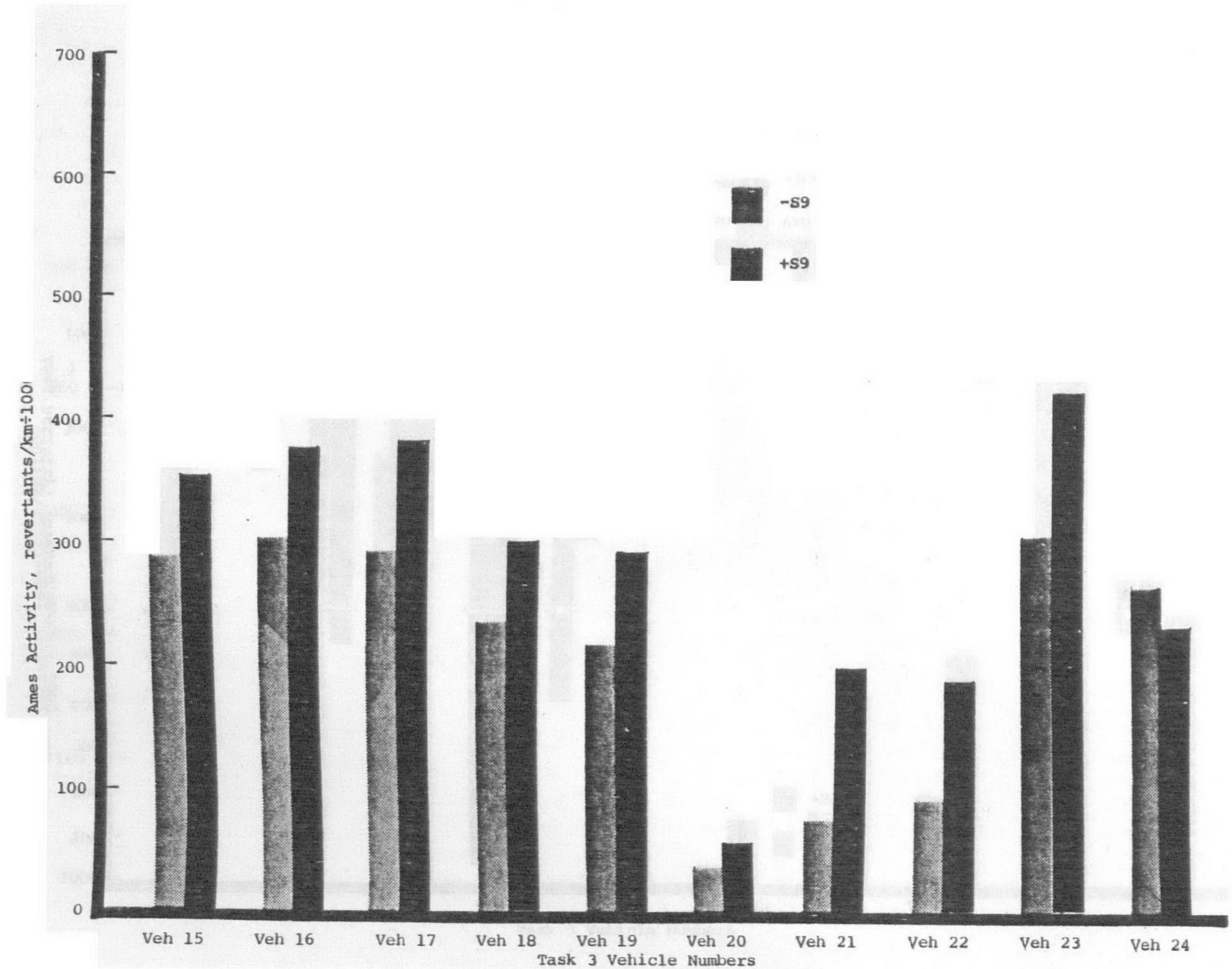


Figure 41. (Continued)

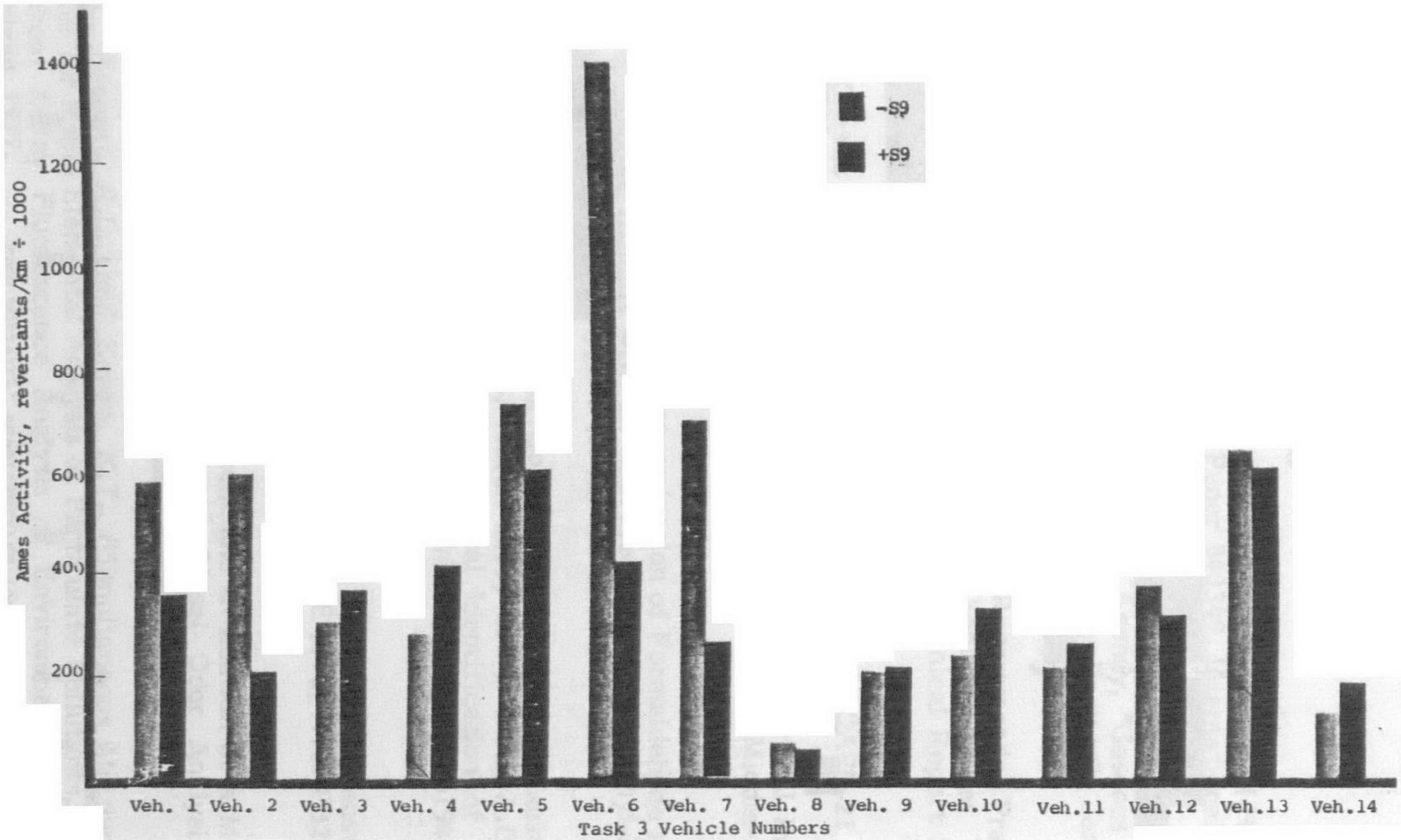


Figure 42. Comparison of TA100 relative Ames activity

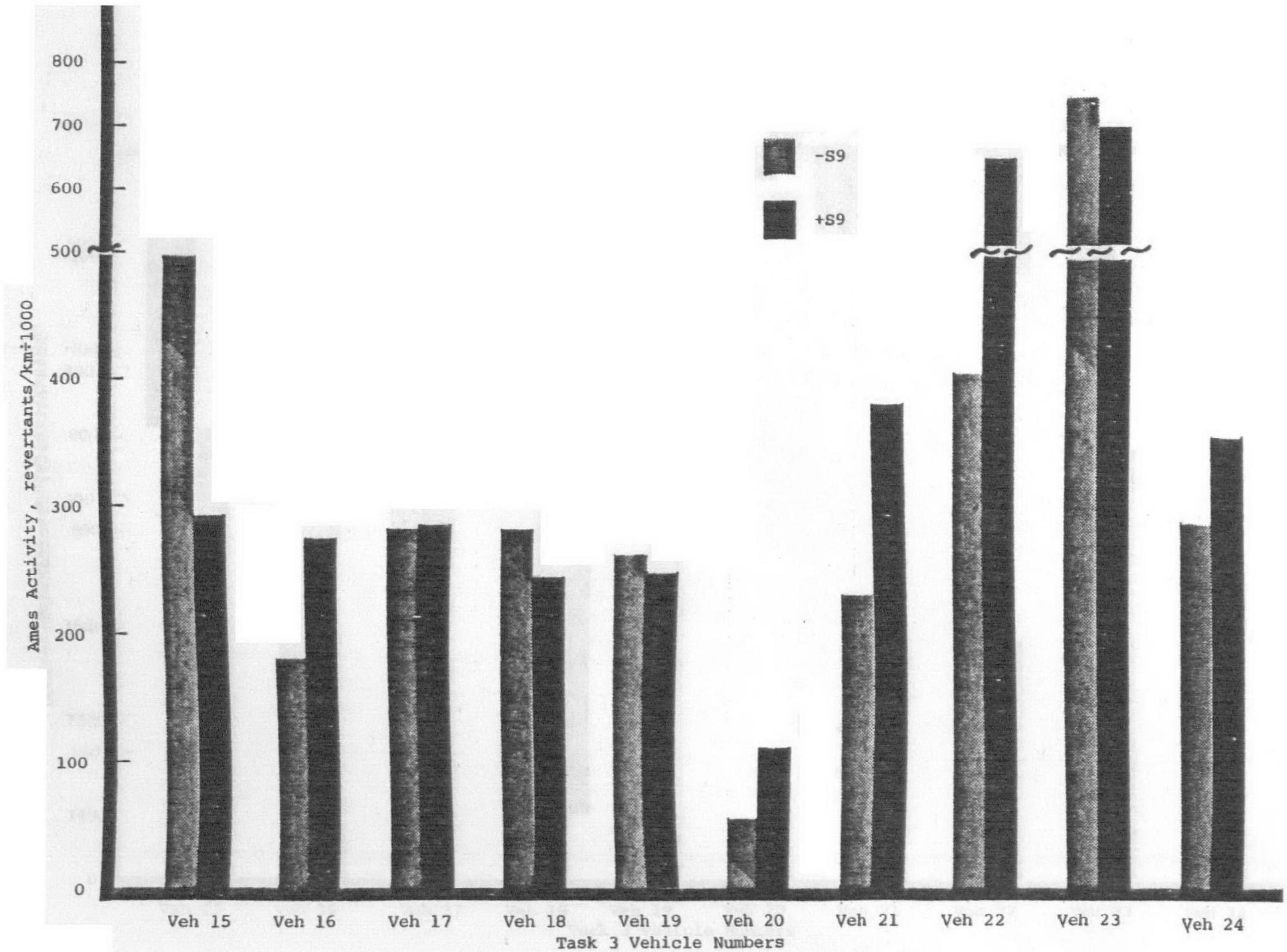


Figure 42 (Continued).

REFERENCES

1. Urban, Charles M., "Dynamometer Simulation of Truck and Bus Road Horsepower for Transient Emissions Evaluations." SAE Paper 840349, International Congress & Exposition, Detroit, Michigan, February 27 -March 2, 1984.

2. Federal Register, Part II, Environmental Protection Agency, "Gaseous Emission Regulations for 1984 and Later Model Year Heavy-Duty Engines", January 21, 1980.

3. France, Chester J., Clemmens, W., and Wyson, Tad, "Recommended Practice for Determining Exhaust Emissions from Heavy-Duty Vehicles Under Transient Conditions," U.S. Environmental Protection Agency, Technical Report SDSB 79-08, February 1979.

4. Heavy-Duty Bus Chassis Cycle No. 2143765149 developed from CAPE-21 data.

5. U.S. Environmental Protection Agency, Interim Report, "Analytical Procedures for Characterizing Unregulated Emissions from Vehicles Using Middle-Distillate Fuels, EPA-600/2-80-068, April, 1980.

6. Lipari, Frank and Swarin, Stephen J., "Determination of Formaldehyde and Other Aldehydes in Automobile Exhaust with an Improved 2,4-Dinitrophenyl-hydrazine Method," Journal of Chromatography, 247 (1982) 297-306.

7. Levins, P.L., "Chemical Analysis of Odor Components in Diesel Exhaust." CRC-APRAC Symposium, Washington D. C., March 1973; CAPE 7-68, A.D. Little First, Second and Third Year Reports, "Chemical Identification of the Odor Components in Diesel Engine Exhaust," NTIS PB194061 (JUL 69), PB194144 (JUN 70), and PB205273 (JUN 71).

8. Levins, P.L., "Analysis of the Odorous Compounds in Diesel Exhaust." Final Report to CRC and EPA Contract No. 68-02-0087, JUNE 1972; NTIS PB228756/AS (SEPT. 1973).

9. CRC-APRAC CAPI 1-64 Report, "Development and Evaluation of a Method for Measurement of Diesel Exhaust Odor Using a Diesel Odor Analysis System (DOAS)." CRC Report No. 507, May 1979.

10. Wagman, J., Bennett, R.L., and Knapp, K.T., "Simultaneous Multiwavelength Spectrometer for Rapid Elemental Analysis of Particulate Pollutants," an Article reprinted from X-Ray Fluorescence Analysis of Environmental Samples, Ann Arbor, Michigan 1977.

11. Private communication between L.R. Smith, SwRI and S. Tejeda, EPA-RTP.

12. Ames, B., McCann, J., Yamasaki, E., "Methods for Detecting Carcinogens and Mutagens with Salmonella/Mammalian-Microsome Mutagenicity Test." Mutation Research, 31, pp. 347-364, 1975.

13. Ames, B.N., "Revised Methods for the Salmonella Mutagenicity Test," Mutation Research, in press, 1983.

14. Code of Federal Regulations, Title 40, Chapter 1, Part 86, Subpart N, Emission Regulations for New Gasoline-Fueled and Diesel Heavy-Duty Engines; Gaseous Exhaust Test Procedures, U.S. Government Printing Office, Washington, D. C., 1982.

APPENDICES

A - Dynamometer Simulation

B - Regulated and Particulate Emissions Results from Chassis and Engine Transient Tests of Task 2 Vehicles

C - Regulated and Particulate Emissions Results from Chassis and Engine Transient Tests of Task 3 Vehicles

D - Summary of Emission Rates from Chassis and Engine Testing

E - Summary of Engine and Chassis Emission Rates in Several Sets of Units

F - Regulated and Particulate Emissions Results from Buses Operated Over the New York Bus Cycle

APPENDIX A

DYNAMOMETER SIMULATION

APPENDIX A

DYNAMOMETER SIMULATION

Using a programmable dynamometer, the procedure developed for road load simulation of a vehicle on the dynamometer involves establishing the speed-power curve, determination of inertia simulation, and determination of system friction.

Speed-Power Curve - The equation selected for calculation of the speed-power curve to be used for evaluations on the chassis dynamometer is as follows:

$$RLP = F \times 0.67(H-0.75)W \times (V/50)^3 + 0.00125 \times LVW \times V/50$$

Where:

RLP = Road Load Power in horsepower
F = 1.00 for tractor-trailer and 0.85 for city bus
H = Average maximum height in feet
W = Average maximum width in feet
LVW = Loaded vehicle weight in pounds

On the Clayton dynamometer with eight and five-eighths inch diameter rolls, the equation for determination of dynamometer torque and load is as follows:

Dynamometer Torque = Hp x 134.8/mph, foot-pounds
Dynamometer Load = Torque x 12/(Load Arm in inches), pounds

Inertia Simulation - In keeping with the general provision in the EPA-Recommended Procedure, the equivalent inertia to set in the dynamometer sytstem for evaluation of a tractor-trailer is to be equal to 70 percent of the gross combined weight. For buses, the equivalent inertia is to be equal to the sum of the empty weight, half passenger load plus the driver (at 150 pounds per person), and the equivalent inertia weight of the non-rotating vehicle wheel assemblies. Available inertia weights were generally in 500 pound increments. Keeping within the 250 pound inertia increment specified in the EPA-Recommended Practice was not possible. Using inertia weights in 500 pound increments for heavy-duty vehicles allowed testing with an actual inertia weight within 1 to 2 percent of the inertia required. In comparison, with light-duty vehicle testing, inertia weights in 125 pound increments are used. For a 4000 pound vehicle, this equates to actual inertia weight being within about three percent of required inertia. The inertia weights used in this program were selected to bring the test inertia within 1 to 2 percent of the total inertia required rather than the 250 pounds specified in the EPA-Recommended Practice.

For actual inertia simulation on the chassis dynamometer, the inertia of the wheel assemblies on the vehicle is to be accounted for. The resultant dynamometer inertia is as follows:

Total Inertia = EID + EIW

Where:
EID = Equivalent inertia of dynamometer system, pounds
EIW = Equivalent inertia of rotating wheels

This total inertia is to be used in the determination of system friction.

System Friction - With the vehicle installed onto the dynamometer and with the appropriate inertia wheels connected, the total system absorbed horsepower is to be determined using coastdowns. This is accomplished by obtaining repeatable 60 to 5 mph coastdown speed vs time data and then solving for the instantaneous decelerations. From the instantaneous decelerations, the power absorption of the vehicle-dynamometer system is determined as a function of vehicle speed. The speed-power curve for programming into the dynamometer controller is then to be determined by the difference between the total power required on the road and the power absorbed by the vehicle-dynamometer system.

The method is briefly described as follows:

(1) Obtain 60 to 5 mph coastdown data
(2) Obtain acceleration using the following equation:

dV/dt = Acceleration = $-(a_0 + a_1V + a_2V^2)$
Where:
a_0 and a_1V represent rolling resistance
a_2V^2 represents rolling resistance
V = velocity of vehicle

Note: An acceptable alternate method is to graphically determine and calculate the acceleration at each five mph increment in vehicle speed.

(3) Calculate the power absorbed using the acceleration values, $F = ma$, and Hp - F x mph/375.

(4) Develop the speed-power curve for programming the dynamometer by subtracting the power absorbed by the vehicle-dynamometer system from the total power required on the road.
(5) Calculate the speed-load curve to program into the dynamometer.

APPENDIX B

REGULATED AND PARTICULATE EMISSIONS RESULTS FROM CHASSIS AND ENGINE TRANSIENT TESTS OF TASK 2 VEHICLES

TABLE B-1. EMISSION RATES FROM VIA CITY BUS NO. 360 POWERED BY A 1982 DETROIT DIESEL 6V-71 (VEHICLE 2-1) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-400-F (DF-1 EMISSIONS TEST FUEL)

	Emission Rate, g/km														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2111	1.24	30.55	1454	12.15	1.70	1.70	21.34	1228	10.58	1.29	1.63	22.66	1261	10.80	1.35
2112	1.71	27.89	1410	12.25	1.50	1.94	19.70	1291	10.84	1.22	1.91	20.87	1309	11.04	1.26
2113	2.68	28.71	1411	12.37	1.55	1.43	20.17	1231	10.61	1.23	1.61	21.39	1258	10.86	1.28
2114	1.81	27.31	1369	11.85	1.55	1.75	20.12	1224	10.56	1.19	1.76	21.15	1245	10.74	1.24
2115	1.87	25.38	1296	11.74	1.35	1.76	20.14	1229	10.67	1.25	1.78	20.89	1239	10.82	1.26
Average	1.86	27.97	1369	12.07	1.53	1.72	20.29	1244	10.65	1.24	1.74	21.39	1262	10.85	1.28
σ	0.52	1.89	60	0.26	0.12	0.18	0.61	32.0	0.11	0.03	0.12	0.740	27.6	0.11	0.043
c.v.	28.0%	6.8%	4.3%	2.2%	8.2%	10.7%	3.0%	2.6%	1.1%	3.0%	7.0%	3.5%	2.2%	1.0%	3.3%

	Emission Rate, g/kg fuel														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2111	2.60	64.16	3056	25.52	3.57	4.24	53.28	3067	26.41	3.22	4.01	54.83	3066	26.29	3.27
2112	3.71	60.48	3058	26.56	3.24	4.62	46.92	3077	25.82	2.90	4.49	48.85	3074	25.92	2.95
2113	5.79	62.00	3049	26.71	3.35	3.57	50.34	3074	26.48	3.08	3.89	52.00	3071	26.51	3.12
2114	4.04	60.92	3056	26.43	3.46	4.39	50.48	3072	26.50	2.98	4.34	51.97	3069	26.49	3.05
2115	4.41	59.84	3057	27.68	3.19	4.40	50.33	3073	26.67	3.12	4.40	51.69	3070	26.81	3.13
Average	4.11	61.48	3055	26.58	3.36	4.24	50.27	3073	26.38	3.06	4.23	51.87	3070	26.40	3.10
σ	1.16	1.69	3.56	0.77	0.15	0.40	2.26	3.65	0.32	0.12	0.26	2.12	2.92	0.32	0.11
c.v.	28.2%	2.8%	0.1%	2.9%	4.6%	9.4%	4.5%	0.1%	1.2%	4.1%	6.2%	4.1%	0.1%	1.2%	3.8%

TABLE B-2. EMISSION RATES FROM A 1982 DETROIT DIESEL 6V-71 (FROM VEHICLE 2-1) OPERATED OVER THE 1984 ENGINE TRANSIENT CYCLE USING EM-400-F (DF-1 EMISSIONS TEST FUEL)

	Emission Rate, g/hp-hr														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2112E	1.75	7.75	842	6.15	0.72	1.84	4.79	770	5.62	0.59	1.84	5.21	780	5.70	0.61
2113E	1.71	7.51	832	6.20	0.64	1.84	4.75	765	5.79	0.52	1.82	5.14	775	5.85	0.54
2114E	1.71	7.72	842	6.08	0.66	1.84	4.91	768	5.61	0.53	1.82	5.31	779	5.68	0.55
2115E	1.59	6.97	838	6.21	0.61	1.79	4.56	769	5.72	0.50	1.76	4.90	779	5.79	0.52
2116E	1.61	7.33	834	5.97	0.59	1.83	4.76	765	5.45	0.54	1.80	5.13	775	5.52	0.55
$\overline{X}$	1.61	7.46	838	6.12	0.64	1.83	4.75	767	5.64	0.53	1.81	5.14	778	5.71	0.55
δ	0.07	0.32	5	0.10	0.04	0.03	0.13	2	0.13	0.03	0.03	0.15	2	0.13	0.03
C.V.	4	4	0	2	8	1	3	0	2	6	2	3	0	2	6

	Emission Rate, g/kg fuel														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO2	NO_x	Part.
2112E	6.46	28.57	3102	22.66	2.67	7.53	19.34	3108	22.68	2.39	7.38	20.66	3107	22.68	2.43
2113E	6.36	27.97	3100	22.08	2.39	7.45	19.33	3109	23.54	2.11	7.29	20.56	3108	23.33	2.16
2114E	6.29	28.46	3104	22.39	2.44	7.46	19.91	3112	22.75	2.16	7.29	21.13	3111	22.70	2.20
2115E	5.88	25.83	3105	22.98	2.28	7.28	18.49	3115	23.17	2.04	7.08	19.54	3114	23.14	2.07
2116E	6.00	27.31	3106	22.22	2.22	7.42	19.33	3106	22.15	2.20	7.22	20.47	3106	22.16	2.20
$\overline{X}$	6.20	27.63	3103	22.5	2.40	7.43	19.3	3110	22.9	2.18	7.25	20.5	3109	22.8	2.21
δ	0.25	1.12	2	0.36	0.17	0.09	0.51	4	0.53	0.13	0.11	0.58	3	0.46	0.13
C.V.	4	4	1	2	7	1	3	0	2	6	2	3	0	2	6

TABLE B-3. EMISSION RATES FROM A DUAL-AXLE TRACTOR POWERED BY A 1980 CUMMINS FORM-350 (VEHICLE 2-2) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2221	3.40	6.14	1487	14.07	1.15	1.87	5.05	1368	14.47	0.87	2.09	5.21	1385	14.41	0.91
2222	3.52	6.06	1465	13.80	1.21	1.90	5.27	1357	14.32	0.90	2.13	5.38	1372	14.25	0.94
2223	2.10	5.08	1435	13.39	1.05	2.11	5.43	1348	14.14	0.94	2.11	5.48	1360	14.03	0.96
2224	2.15	6.52	1462	14.43	1.16	1.69	5.83	1378	14.60	0.98	1.76	5.93	1390	14.58	1.01
2225	3.61	6.78	1428	13.81	1.18	1.96	5.62	1360	14.36	0.99	2.20	5.79	1370	14.28	1.02
$\bar{X}$	2.96	6.26	1455	13.90	1.15	1.91	5.44	1362	14.38	0.94	2.06	5.56	1375	14.31	0.97
S.D.	0.76	0.39	24	0.38	0.06	0.15	0.30	11	0.17	0.05	0.17	0.29	12	0.20	0.05
C.V.	25	6	2	3	5	8	6	1	1	5	8	5	1	1	5

	Emission Rate, g/kg fuel														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2221	7.17	12.95	3137	29.68	2.43	4.30	11.62	3148	33.30	2.00	4.71	11.81	3147	32.78	2.06
2222	7.53	12.96	3134	29.52	2.59	4.41	12.22	3147	33.21	2.09	4.85	12.33	3145	32.68	2.16
2223	4.60	12.71	3144	29.34	2.30	4.92	12.67	3144	32.98	2.19	4.88	12.67	3144	32.46	2.21
2224	4.62	14.02	3144	31.03	2.49	3.86	13.31	3146	33.33	2.24	3.97	13.41	3145	33.00	2.27
2225	7.93	14.87	3131	30.28	2.59	4.53	13.00	3145	33.21	2.29	5.02	13.26	3143	32.79	2.33
$\bar{X}$	6.37	13.5	3138	30.0	2.48	4.40	12.6	3146	33.2	2.16	4.69	12.7	3145	32.7	2.21
S.D.	1.63	0.9	6	0.7	0.12	0.38	0.7	2	0.1	0.12	0.42	0.7	2	0.2	0.10
C.V.	26	7	0	2	5	9	5	0	0	5	9	5	0	1	5

NOTE: $\bar{X}$ = Average, S.D. = Standard Deviation, C.V. = Coefficient of Variation

TABLE B- 4. EMISSION RATES FROM A 1980 CUMMINS FORM-350 (FROM VEHICLE 2-2) OPERATED OVER THE 1984 ENGINE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/hp-hr														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2221E	0.97	2.28	626	6.51	0.42	0.93	2.11	592	6.81	0.39	0.94	2.13	597	6.77	0.39
2222E	1.10	2.31	624	6.53	0.42	0.82	2.06	587	6.97	0.38	0.86	2.10	592	6.91	0.39
2223E	0.94	2.37	621	6.54	0.47	0.93	2.18	586	6.88	0.41	0.93	2.21	591	6.83	0.42
2224E	0.95	2.36	613	6.52	0.46	0.97	2.18	581	6.68	0.40	0.97	2.21	586	6.66	0.41
2225E	0.99	2.28	613	6.31	0.45	0.88	2.08	580	6.44	0.38	0.90	2.11	585	6.42	0.39
$\overline{X}$	0.99	2.32	619	6.48	0.44	0.91	2.12	585	6.76	0.39	0.92	2.15	590	6.72	0.40
S.D.	0.07	0.04	6	0.08	0.02	0.06	0.06	5	0.21	0.01	0.04	0.05	5	0.19	0.01
C.V.	7	2	1	2	5	6	3	1	3	3	4	2	1	3	4

	Emission Rate, g/kg fuel														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2221E	4.87	11.46	3146	32.73	2.11	4.96	11.23	3151	36.23	2.07	4.95	11.26	3150	35.73	2.08
2221E	5.60	11.65	3147	32.93	2.12	4.44	11.04	3148	37.40	2.02	4.61	11.13	3148	36.76	2.03
2223E	4.75	12.00	3143	33.09	2.40	5.00	11.68	3144	36.88	2.22	4.96	11.73	3144	36.34	2.25
2225E	4.87	12.15	3149	33.49	2.34	5.26	11.86	3154	36.28	2.18	5.20	11.90	3153	35.88	2.20
2225E	5.10	11.69	3149	32.45	2.30	4.78	11.26	3150	34.94	2.09	4.83	11.32	3150	34.58	2.12
$\overline{X}$	5.04	11.8	3147	32.9	2.25	4.89	11.4	3149	36.4	2.12	4.91	11.5	3149	35.9	2.14
S.D.	0.34	0.28	2	0.4	0.13	0.30	0.3	4	0.9	0.08	0.21	0.3	3	0.8	0.09
C.V.	7	2	0	1	6	6	3	0	3	4	4	3	0	2	4

NOTE: $\overline{X}$ = Average, S.D. = Standard Deviation, C.V. = Coefficient of Variation

TABLE B-5. EMISSION RATES FROM A DUAL-AXLE TRACTOR POWERED BY A 1980 DETROIT DIESEL 8V-92TA (VEHICLE 2-3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rates, g/km														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2321	1.92	2.39	1491	12.71	0.94	1.88	2.07	1389	13.49	0.79	1.89	2.12	1404	13.38	0.81
2322	1.96	2.86	1537	13.30	0.90	1.45	2.46	1406	13.42	0.83	1.52	2.52	1425	13.40	0.84
2323	1.91	2.48	1554	13.54	0.91	1.67	1.96	1424	12.82	0.85	1.70	2.03	1443	12.92	0.86
2324	1.73	2.51	1560	14.40	0.94	1.80	2.24	1425	13.53	0.91	1.79	2.28	1444	13.65	0.91
2325	1.52	2.60	1514	13.72	1.01	1.71	2.21	1386	13.62	0.90	1.68	2.27	1404	13.63	0.92
$\bar{X}$	1.81	2.57	1531	13.53	0.94	1.70	2.19	1406	13.38	0.86	1.72	2.24	1424	13.40	0.87
S.D.	0.18	0.18	29	0.62	0.04	0.16	0.19	19	0.32	0.05	0.14	0.19	20	0.29	0.05
C.V.	10	7	2	5	5	10	9	1	2	6	8	8	1	2	5

	Emission Rate, g/kg fuel														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2321	4.07	5.06	3158	26.91	1.99	4.28	4.71	3159	30.68	1.80	4.25	4.76	3159	30.14	1.83
2322	4.03	5.87	3157	27.31	1.86	3.26	5.53	3160	30.17	1.87	3.37	5.58	3160	29.76	1.87
2323	3.88	5.04	3159	27.53	1.85	3.71	4.35	3161	28.45	1.90	3.73	4.45	3161	28.32	1.89
2324	3.51	5.09	3161	29.18	1.90	3.99	4.97	3159	30.00	2.02	3.92	4.98	3159	29.88	2.00
2325	3.17	5.43	3161	28.64	2.10	3.90	5.04	3160	31.05	2.05	3.79	5.09	3160	30.71	2.06
$\bar{X}$	3.73	5.30	3159	27.91	1.94	3.83	4.92	3160	30.07	1.93	3.81	4.97	3160	29.76	1.93
S.D.	0.38	0.36	2	1.0	0.11	0.38	0.44	1	1.00	0.11	0.32	0.42	1	0.89	0.10
C.V.	10	7	<1	3	5	10	9	<1	3	5	8	8	<1	3	5

TABLE B-6. EMISSION RATES FROM A 1980 DETROIT DIESEL 8V-92TA (FROM VEHICLE 2-3) OPERATED OVER THE 1984 ENGINE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

Emission Rate, g/hp-hr

	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2322E	0.65	1.88	663	6.41	0.45	0.58	2.08	635	6.86	0.38	0.59	2.05	639	6.80	0.39
2323E	0.66	1.93	666	6.24	0.47	0.59	2.11	636	6.69	0.38	0.60	2.08	640	6.63	0.39
2324E	0.64	1.72	656	6.13	0.43	0.55	1.87	638	6.54	0.35	0.56	1.85	641	6.48	0.36
2325E	0.70	1.87	661	6.27	0.61	0.60	2.00	645	6.76	0.40	0.61	1.98	647	6.69	0.43
2326E	0.81	1.71	672	6.53	0.58	0.59	1.71	646	7.17	0.38	0.62	1.71	650	7.08	0.41
$\bar{X}$	0.69	1.82	664	6.32	0.51	0.58	1.95	640	6.80	0.38	0.60	1.93	643	6.74	0.40
S.D.	0.07	0.10	6	0.16	0.08	0.02	0.17	5	0.24	0.02	0.02	0.15	5	0.22	0.03
C.V.	10	6	1	2	16	3	8	1	3	5	4	8	1	3	7

Emission Rate, g/kg fuel

	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2322E	3.09	8.90	3156	30.50	2.13	2.89	10.33	3152	34.07	1.88	2.92	10.13	3153	33.56	1.92
2323E	3.11	9.15	3156	29.54	2.23	2.93	10.48	3159	33.22	1.87	2.96	10.29	3159	32.69	1.92
2324E	3.06	8.27	3166	29.57	2.06	2.73	9.23	3159	33.36	1.75	2.78	9.09	3160	32.82	1.79
2325E	3.35	8.93	3157	29.93	2.93	2.96	9.78	3157	33.10	1.94	3.02	9.66	3157	32.65	2.08
2326E	3.79	8.04	3161	30.74	2.71	2.88	8.36	3161	35.11	1.86	3.10	8.31	3161	34.49	1.98
$\bar{X}$	3.28	8.66	3159	30.1	2.41	2.88	9.64	3158	33.8	1.86	2.97	9.50	3158	33.2	1.94
S.D.	0.31	0.48	4	0.5	0.39	0.09	0.87	3	0.8	0.07	0.15	0.81	3	0.8	0.11
C.V.	0	5	0	2	16	3	9	0	2	4	5	9	0	2	5

NOTE: $\bar{X}$ = Average, S.D. = Standard Deviation, C.V. = Coefficient of Variation

TABLE B-7. EMISSION RATES FROM A SINGLE-AXLE TRACTOR POWERED BY A 1979 INTERNATIONAL HARVESTER DT-466B (VEHICLE 2-4) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2421	1.22	3.26	1052	9.91	0.84	1.09	2.79	1010	9.43	0.82	1.11	2.85	1016	9.50	0.82
2422	1.28	3.28	1073	9.79	0.74	1.05	2.73	1015	9.08	0.72	1.08	2.81	1023	9.18	0.72
2423	1.31	3.11	1045	9.00	0.75	1.21	2.59	965	8.11	0.71	1.22	2.66	976	8.24	0.72
2424	1.26	3.28	1100	10.18	0.81	1.11	2.88	974	8.77	0.76	1.13	2.94	992	8.97	0.77
2425	1.44	3.45	1082	9.95	0.83	1.16	2.77	967	8.43	0.86	1.20	2.86	983	8.65	0.86
$\bar{X}$	1.30	3.28	1070	9.77	0.79	1.12	2.75	986	8.76	0.77	1.15	2.82	998	8.91	0.78
S.D.	0.08	0.12	22	0.45	0.05	0.06	0.11	24	0.52	0.06	0.06	0.10	21	0.49	0.06
C.V.	6	4	2	5	6	6	4	2	6	8	5	4	2	5	8

	Emission Rate, g/kg fuel														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2421	3.66	9.77	3153	29.71	2.51	3.74	8.52	3155	29.34	2.83	3.73	8.70	3154	29.39	2.79
2422	3.76	9.64	3153	28.76	2.18	3.27	8.49	3156	28.24	2.24	3.34	8.66	3155	28.32	2.23
2423	3.95	9.38	3152	27.14	2.26	3.95	8.46	3153	26.49	2.33	3.95	8.59	3153	26.58	2.32
2424	3.61	9.40	3153	29.19	2.33	3.59	9.33	3154	28.40	2.46	3.60	9.34	3154	28.51	2.44
2425	4.19	10.04	3150	28.96	2.41	3.78	9.03	3153	27.49	2.79	3.84	9.18	3152	27.70	2.74
$\bar{X}$	3.83	9.65	3152	28.75	2.34	3.67	8.77	3154	27.99	2.53	3.69	8.89	3154	28.10	2.50
S.D.	0.24	0.27	1	0.97	0.13	0.26	0.39	1	1.07	0.27	0.24	0.34	1	1.04	0.25
C.V.	6	3	0	3	5	7	4	0	4	11	6	4	0	4	10

TABLE B-8. EMISSION RATES FROM A 1979 INTERNATIONAL HARVESTER DT-466B (FROM VEHICLE 2-4) OPERATED OVER THE 1984 EPA ENGINE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/hp-hr														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2421E	0.98	2.62	713	6.61	0.56	0.80	2.14	704	6.46	0.52	0.83	2.21	705	6.48	0.53
2422E	0.91	2.48	711	6.79	0.52	0.77	2.00	702	6.50	0.50	0.79	2.07	703	6.54	0.50
2423E	0.95	2.53	749	7.50	0.54	0.75	2.01	707	6.89	0.49	0.78	2.08	713	6.98	0.50
2424E	0.91	2.51	723	7.16	0.51	0.83	2.07	695	6.81	0.48	0.84	2.13	699	6.86	0.48
2425E	0.96	2.47	710	6.92	0.59	0.77	1.96	684	6.49	0.53	0.80	2.03	688	6.55	0.54
$\bar{X}$	0.94	2.52	721	7.00	0.54	0.78	2.04	698	6.63	0.50	0.81	2.10	702	6.68	0.51
S.D.	0.03	0.06	16	0.35	0.03	0.03	0.07	9	0.20	0.02	0.03	0.07	9	0.22	0.02
C.V.	3	2	2	5	6	4	3	1	3	4	3	3	1	3	5

	Emission Rate, g/kg fuel														
	Cold Start					Hot Start					Composite				
Test	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.	HC	CO	CO_2	NO_x	Part.
2421E	4.43	11.58	3142	29.24	2.48	3.58	9.57	3154	28.96	2.33	3.69	9.86	3152	29.00	2.35
2422E	4.04	10.99	3156	30.13	2.29	3.46	8.99	3158	29.23	2.26	3.54	9.28	3158	29.36	2.26
2423E	3.98	10.63	3150	31.54	2.29	3.33	9.00	3163	30.80	2.21	3.42	9.23	3161	30.91	2.22
2424E	3.96	10.94	3149	31.17	2.24	3.80	9.42	3159	30.95	2.18	3.82	9.64	3158	30.98	2.19
2425E	4.27	10.96	3152	30.73	2.61	3.59	9.07	3162	30.00	2.46	3.69	9.34	3161	30.10	2.48
$\bar{X}$	4.12	11.02	3150	30.56	2.38	3.55	9.21	3159	29.99	2.29	3.63	9.47	3158	30.07	2.30
S.D.	0.18	0.35	5	0.91	0.16	0.17	0.27	4	0.90	0.11	0.15	0.27	4	0.89	0.12
C.V.	4	3	<1	3	7	5	3	<1	3	5	4	3	<1	3	5

APPENDIX C

REGULATED AND PARTICULATE EMISSIONS RESULTS FROM CHASSIS AND ENGINE TRANSIENT TESTS OF TASK 3 VEHICLES

TABLE C-1. EMISSION RATES FROM VEHICLE 3-1 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x(1)	Part.	HC	CO	CO_2	NO_x(1)	Part.	HC	CO	CO_2	NO_x(1)	Part.
3121	2.68	4.84	1264	9.01	1.42	2.22	3.59	1156	9.34	1.16	2.29	3.77	1171	9.29	1.20
3122	2.59	4.34	1230	8.76	1.25	2.20	3.65	1150	8.74	1.13	2.26	3.75	1161	8.74	1.15
3123	2.38	4.12	1263	9.05	1.19	1.93	3.69	1169	8.93	1.13	1.99	3.75	1182	8.95	1.14
Avg.	2.55	4.43	1252	8.94	1.29	2.12	3.64	1158	9.00	1.14	2.18	3.76	1171	8.99	1.16

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x(1)	Part.	HC	CO	CO_2	NO_x(1)	Part.	HC	CO	CO_2	NO_x(1)	Part.
3121	6.65	12.01	3138	22.37	3.52	6.04	9.77	3145	25.41	3.16	6.13	10.09	3144	24.97	3.21
3122	6.61	11.08	3142	22.37	3.19	6.02	9.98	3145	23.90	3.09	6.10	10.14	3144	23.68	3.10
3123	5.92	10.26	3144	22.53	2.96	5.20	9.93	3147	24.04	3.04	5.30	9.98	3146	23.82	3.03
Avg.	6.39	11.12	3141	22.4	3.22	5.75	9.89	3146	24.4	3.10	5.84	10.07	3145	24.2	3.11

(1) NO_x from bag measurement

TABLE C-2. EMISSION RATES FROM VEHICLE 3-2 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.
3221	1.16	3.37	1069	11.48	0.87	1.14	2.52	995	10.67	0.80	1.14	2.64	1006	10.79	0.81
3222	1.02	3.36	1061	11.69	0.84	1.00	2.55	1002	10.71	0.79	1.00	2.67	1010	10.85	0.80
Avg.	1.09	3.37	1065	11.6	0.86	1.07	2.54	998	10.7	0.80	1.07	2.66	1008	10.8	0.81

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.
3221	3.42	9.94	3152	33.85	2.57	3.61	7.99	3154	33.82	2.54	3.59	8.27	3154	33.83	2.54
3222	3.03	9.99	3155	34.76	2.50	3.15	8.03	3156	33.73	2.49	3.13	8.31	3155	33.88	2.49
Avg.	3.23	9.97	3154	34.3	2.54	3.38	8.01	3155	33.8	2.52	3.36	8.29	3154	33.9	2.52

(1) NO_x from bag measurement

TABLE C-3. EMISSION RATES FROM VEHICLE 3-3 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
3321	2.04	7.10	1185	9.50	1.66	2.00	5.75	1061	9.03	1.42	2.01	5.94	1079	9.10	1.45
3322	2.08	6.59	1150	9.34	1.44	2.29	5.56	1038	9.17	1.41	2.26	5.71	1054	9.19	1.41
Avg.	2.06	6.85	1168	9.42	1.55	2.15	5.66	1050	9.10	1.42	2.14	5.83	1066	9.15	1.43

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
3321	5.39	18.77	3133	25.12	4.39	5.91	16.98	3133	26.66	4.19	5.83	17.23	3133	26.44	4.22
3322	5.67	17.96	3135	25.46	3.93	6.91	16.78	3133	27.68	4.26	6.73	16.95	3133	27.36	4.21
Avg.	5.53	18.4	3134	25.3	4.16	6.41	16.8	3133	27.2	4.23	6.28	17.1	3133	26.9	4.22

(1) NO_x from bag measurement

TABLE C-4. EMISSIONS RATES FROM VEHICLE 3-4 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x[(1)]	Part.	HC	CO	CO_2	NO_x[(1)]	Part.	HC	CO	CO_2	NO_x[(1)]	Part.
3421	1.80	3.26	1586	15.63	1.37	1.73	3.21	1519	15.98	1.28	1.74	3.22	1529	15.93	1.29
3423	1.45	2.71	1597	14.32	1.30	1.57	2.95	1521	13.17	1.21	1.55	2.92	1532	13.33	1.22
Avg.	1.63	2.99	1592	15.0	1.34	1.65	3.08	1520	14.6	1.25	1.65	3.07	1530	14.6	1.26

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x[(1)]	Part.	HC	CO	CO_2	NO_x[(1)]	Part.	HC	CO	CO_2	NO_x[(1)]	Part.
3421	3.58	6.49	3157	31.12	2.73	3.60	6.67	3158	33.23	2.66	3.60	6.65	3158	32.93	2.67
3423	2.87	5.36	3161	28.34	2.57	3.26	6.13	3160	27.36	2.51	3.21	6.02	3160	27.50	2.52
Avg.	3.23	5.93	3159	29.7	2.65	3.43	6.40	3159	30.3	2.59	3.41	6.34	3159	30.2	2.60

[(1)] NO_x from bag measurement

TABLE C-5. EMISSION RATES FROM VEHICLE 3-5 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

Emission Rate, g/km

Test	Cold-Start HC	Cold-Start CO	Cold-Start CO_2	Cold-Start NO_x[1]	Cold-Start Part.	Hot-Start HC	Hot-Start CO	Hot-Start CO_2	Hot-Start NO_x[1]	Hot-Start Part.	Composite HC	Composite CO	Composite CO_2	Composite NO_x[1]	Composite Part.
3521	1.42	3.54	1718	16.33	1.44	1.76	3.45	1651	16.69	1.15	1.71	3.46	1661	16.64	1.19
3522	1.80	4.38	1680	15.49	1.44	1.73	3.50	1594	15.84	1.14	1.74	3.63	1606	15.79	1.18
Avg.	1.61	3.96	1699	15.9	1.44	1.75	3.48	1622	16.3	1.15	1.73	3.55	1634	16.2	1.19

Emission Rate, g/kg fuel

Test	Cold-Start HC	Cold-Start CO	Cold-Start CO_2	Cold-Start NO_x[1]	Cold-Start Part.	Hot-Start HC	Hot-Start CO	Hot-Start CO_2	Hot-Start NO_x[1]	Hot-Start Part.	Composite HC	Composite CO	Composite CO_2	Composite NO_x[1]	Composite Part.
3521	2.61	6.52	3162	30.06	2.65	3.37	6.60	3159	31.93	2.20	3.26	6.59	3159	31.67	2.26
3522	3.38	8.23	3156	29.10	2.71	3.43	6.93	3157	31.38	2.26	3.42	7.12	3105	31.05	2.32
Avg.	3.00	7.38	3159	29.6	2.68	3.40	6.77	3158	31.7	2.23	3.34	6.86	3132	31.4	2.29

[1] NO_x from bag measurement

TABLE C-6. EMISSION RATES FROM VEHICLE 3-6 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
3621	2.88	17.39	1670	14.40	2.40	3.27	15.29	1482	13.97	1.88	3.21	15.59	1508	14.03	1.95
3622	2.63	17.57	1621	13.99	2.00	3.05	15.02	1489	13.92	1.78	2.99	15.38	1508	13.93	1.81
Avg.	2.76	17.5	1645	14.2	2.20	3.16	15.2	1486	14.0	1.83	3.10	15.5	1508	14.0	1.88

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
3621	5.37	32.40	3112	26.83	4.47	6.86	32.07	3108	29.30	3.94	6.64	32.11	3109	28.95	4.02
3622	5.05	33.72	3111	26.85	3.84	6.37	31.37	3110	29.07	3.72	6.18	31.70	3110	28.75	3.73
Avg.	5.21	33.1	3112	26.8	4.16	6.62	31.7	3109	29.2	3.83	6.41	31.9	3110	28.8	3.88

(1) NO_x from bag measurement

TABLE C-7. EMISSION RATES FROM VEHICLE 3-7 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x(1)	Part.	HC	CO	CO_2	NO_x(1)	Part.	HC	CO	CO_2	NO_x(1)	Part.
3721	2.42	7.97	1490	15.13	1.35	2.04	6.69	1318	15.13	1.13	2.09	6.87	1343	15.13	1.16
3722	2.18	7.03	1471	14.81	1.32	2.19	6.38	1330	15.45	1.13	2.20	6.49	1354	15.41	1.16
Avg.	2.30	7.50	1480	15.0	1.34	2.12	6.54	1324	15.3	1.13	2.15	6.68	1348	15.3	1.16

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x(1)	Part.	HC	CO	CO_2	NO_x(1)	Part.	HC	CO	CO_2	NO_x(1)	Part.
3721	5.09	16.78	3136	31.85	2.84	4.86	15.93	3138	36.02	2.69	4.89	16.05	3138	35.42	2.71
3222	4.65	15.01	3140	31.62	2.82	5.17	15.06	3140	36.47	2.67	5.10	15.05	3140	35.78	2.69
Avg.	4.87	15.9	3138	31.7	2.83	5.02	15.5	3139	36.2	2.68	5.00	15.6	3139	35.6	2.70

(1) NO_x from bag measurement

TABLE C-8. EMISSION RATES FROM VEHICLE 3-8 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-455-F (NO. 1 EMISSIONS TEST FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
3831	1.81	68.78	1496	11.82	5.78	1.45	51.20	1156	9.75	4.21	1.50	53.71	1205	10.05	4.43
3832	1.74	68.01	1389	11.89	5.13	1.58	51.01	1144	10.08	4.29	1.60	53.44	1179	10.34	4.41
Avg.	1.78	68.4	1442	11.9	5.46	1.52	51.1	1150	9.92	4.25	1.55	53.6	1192	10.2	4.42

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
3831	3.56	135.2	2941	23.23	11.36	3.70	130.5	2947	24.86	10.73	3.68	131.2	2946	24.63	10.82
3832	3.67	143.4	2928	25.06	10.81	4.07	131.3	2945	25.95	11.04	4.01	133.0	2943	25.82	11.01
Avg.	3.62	139.3	2934	24.2	11.1	3.89	130.9	2946	25.4	10.9	3.85	132.1	2944	25.2	10.9

(1) NO_x from bag measurement

TABLE C-9. EMISSION RATES FROM VEHICLE 3-9 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-455-F (NO. 1 EMISSIONS TEST FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
3931	1.85	22.68	1372	15.43	1.83	1.85	18.38	1193	13.75	1.51	1.85	18.99	1219	13.99	1.56
3932	1.70	21.60	1326	15.29	1.69	1.78	16.10	1162	13.34	1.26	1.77	16.89	1185	13.62	1.32
Avg.	1.78	22.1	1349	15.4	1.76	1.82	17.2	1178	13.5	1.38	1.81	17.9	1202	13.8	1.44

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
3931	4.14	50.76	3071	34.54	4.10	4.77	47.38	3075	35.44	3.89	4.68	47.86	3075	35.31	3.92
3932	3.94	50.06	3073	35.44	3.92	4.72	42.70	3082	35.38	3.34	4.61	43.75	3081	35.39	3.42
Avg.	4.04	50.4	3072	35.0	4.01	4.75	45.0	3078	35.4	3.62	4.65	45.8	3078	35.4	3.67

(1) NO_x from bag measurement

TABLE C-10. EMISSION RATES FROM VEHICLE 3-10 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

Emission Rate, g/km

Test	Cold-Start HC	Cold-Start CO	Cold-Start CO_2	Cold-Start NO_x(1)	Cold-Start Part.	Hot-Start HC	Hot-Start CO	Hot-Start CO_2	Hot-Start NO_x(1)	Hot-Start Part.	Composite HC	Composite CO	Composite CO_2	Composite NO_x(1)	Composite Part.
31021	1.19	6.18	1445	19.38	----(2)	1.16	5.04	1283	16.73	1.59	1.16	5.20	1306	17.11	----(2)
31022	1.15	5.86	1449	18.64	1.51	1.14	4.67	1193	17.77	1.32	1.14	4.84	1230	17.89	1.35
Avg.	1.17	6.02	1447	19.0	1.51	1.15	4.86	1238	17.2	1.46	1.15	5.02	1268	17.5	1.47

Emission Rate, g/kg fuel

Test	Cold-Start HC	Cold-Start CO	Cold-Start CO_2	Cold-Start NO_x(1)	Cold-Start Part.	Hot-Start HC	Hot-Start CO	Hot-Start CO_2	Hot-Start NO_x(1)	Hot-Start Part.	Composite HC	Composite CO	Composite CO_2	Composite NO_x(1)	Composite Part.
31021	2.59	13.47	3150	42.25	----(2)	2.85	12.37	3150	41.07	3.90	2.81	12.53	3150	41.24	----(2)
31022	2.50	12.75	3152	40.55	3.28	3.01	12.33	3150	46.92	3.49	2.94	12.39	3150	46.01	3.46
Avg.	2.55	13.11	3151	41.4	3.28	2.93	12.4	3150	44.0	3.70	2.88	12.5	3150	43.6	3.64

(1) NO_x from bag measurement
(2) No valid particulate data

TABLE C-11. EMISSION RATES FROM VEHICLE 3-11 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.
31121	0.96	5.65	1440	14.43	1.86	0.98	5.06	1358	14.07	1.75	0.98	5.14	1370	14.12	1.77
31122	0.99	5.79	1443	16.17	1.77	0.91	5.62	1393	15.08	1.84	0.92	5.64	1400	15.24	1.83
Avg.	0.98	5.72	1442	15.3	1.82	0.95	5.34	1376	14.6	1.80	0.95	5.39	1385	14.7	1.80

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.
31121	2.10	12.37	3153	31.59	4.07	2.28	11.75	3155	32.68	4.07	2.25	11.84	3154	32.53	4.07
31122	2.16	12.65	3153	35.33	3.87	2.06	12.73	3156	34.17	4.17	2.07	12.72	3156	34.34	4.13
Avg.	2.13	12.5	3153	33.5	3.97	2.17	12.2	3156	33.4	4.12	2.16	12.3	3155	33.4	4.10

[1] NO_x from bag measurement

TABLE C-12. EMISSION RATES FROM VEHICLE 3-12 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x[(1)]	Part.	HC	CO	CO_2	NO_x[(1)]	Part.	HC	CO	CO_2	NO_x[(1)]	Part.
31221	2.15	13.59	1597	17.93	3.10	1.51	11.79	1495	18.73	2.64	1.60	12.05	1510	18.62	2.71
31222	2.11	14.53	1596	18.78	3.27	1.57	11.92	1510	18.57	2.93	1.65	12.29	1522	18.60	2.98
Avg.	2.13	14.1	1596	18.4	3.19	1.54	11.9	1502	18.6	2.79	1.63	12.2	1516	18.6	2.85

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x[(1)]	Part.	HC	CO	CO_2	NO_x[(1)]	Part.	HC	CO	CO_2	NO_x[(1)]	Part.
31221	4.21	26.59	3125	35.09	6.07	3.16	24.68	3130	39.21	5.53	3.31	24.96	3129	38.63	5.60
31222	4.13	28.42	3122	36.73	6.40	3.25	24.71	3130	38.49	6.07	3.38	25.24	3129	38.24	6.12
Avg.	4.17	27.5	3124	35.9	6.24	3.21	24.7	3130	38.8	5.80	3.35	25.1	3129	38.4	5.86

(1) NO_x from bag measurement

TABLE C-13. EMISSION RATES FROM VEHICLE 3-13 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31321	1.79	10.76	1622	21.59	1.94	1.17	7.19	1523	23.76	1.40	1.26	7.70	1537	23.45	1.48
31322	1.58	10.57	1754	23.76	1.97	1.14	7.97	1655	26.06	1.68	1.20	8.34	1503	25.73	1.69
Avg.	1.69	10.7	1688	22.7	1.96	1.16	7.58	1589	24.9	1.54	1.23	8.02	1520	24.6	1.59

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31321	3.46	20.80	3135	41.73	3.75	2.42	14.86	3148	49.11	2.89	2.57	15.71	3146	48.06	3.02
31322	2.83	18.92	3140	42.54	3.53	2.17	15.15	3149	49.59	3.20	2.26	15.70	3148	48.58	3.24
Avg.	3.15	19.9	3138	42.1	3.64	2.30	15.0	3148	49.4	3.05	2.42	15.70	3147	48.3	3.13

(1) NO_x from bag measurement

TABLE C-14. EMISSION RATES FROM VEHICLE 3-14 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31421	2.21	7.98	1447	13.48	1.37	1.75	7.56	1360	15.78	1.18	1.82	7.62	1372	15.45	1.21
31422	2.18	7.46	1405	13.86	1.46	1.75	7.20	1350	14.93	1.26	1.81	7.24	1358	14.78	1.29
Avg.	2.20	7.72	1426	13.7	1.42	1.75	7.38	1355	15.4	1.22	1.81	7.43	1365	15.1	1.25

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31421	4.79	17.30	3138	29.23	2.97	4.04	17.45	3140	36.43	2.72	4.15	17.43	3140	35.40	2.76
31422	4.87	16.67	3139	30.69	3.26	4.07	16.75	3141	34.73	2.93	4.19	16.74	3140	34.19	2.98
Avg.	4.83	17.0	3138	30.1	3.12	4.06	17.1	3140	35.6	2.83	4.17	17.1	3140	34.8	2.87

(1) NO_x from bag measurement

TABLE C-15. EMISSION RATES FROM VEHICLE 3-15 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x [1]	Part.	HC	CO	CO_2	NO_x [1]	Part.	HC	CO	CO_2	NO_x [1]	Part.
31521	2.19	22.82	1639	13.61	2.82	2.06	21.57	1547	15.38	2.72	2.08	21.75	1560	15.13	2.73
31522	2.11	18.48	1626	15.23	2.48	2.00	17.75	1508	14.32	2.45	2.02	17.85	1525	14.45	2.45
Avg.	2.15	20.6	1632	14.4	2.65	2.03	19.7	1528	14.8	2.59	2.05	19.8	1542	14.8	2.59

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x [1]	Part.	HC	CO	CO_2	NO_x [1]	Part.	HC	CO	CO_2	NO_x [1]	Part.
31521	4.14	43.14	3098	25.73	5.33	4.13	43.20	3098	30.80	5.45	4.13	43.19	3098	30.80	5.43
31522	4.04	35.37	3112	29.15	4.75	4.12	36.58	3108	29.51	5.05	4.11	36.41	3108	29.46	5.01
Avg.	4.09	39.3	3105	27.4	5.04	4.13	39.9	3103	30.2	5.25	4.12	39.8	3103	29.8	5.22

[1] NO_x from bag measurement

TABLE C-16. EMISSION RATES FROM VEHICLE 3-16 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

Emission Rate, g/km

	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31621	1.37	5.48	1693	22.61	1.80	1.42	6.03	1574	22.04	1.32	1.41	5.95	1591	22.12	1.39
31622	----(2)	5.67	1714	22.34	1.56	----(2)	6.00	1594	22.28	1.32	----(2)	5.95	1611	22.29	1.35
31623	1.35	4.91	1665	19.96	1.46	1.32	5.01	1564	21.30	1.23	1.32	5.00	1578	21.11	1.26
Avg.	1.36	5.35	1691	12.6	1.61	1.37	5.68	1577	21.9	1.29	1.37	5.63	1593	21.8	1.33

Emission Rate, g/kg fuel

	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31621	2.55	10.21	3155	42.14	3.35	2.84	12.07	3151	44.13	2.64	2.80	11.81	3152	43.84	2.74
31622	----(2)	10.47	3166	41.27	2.88	----(2)	11.87	3154	44.08	2.61	----(2)	11.67	3156	43.68	2.65
31623	2.56	9.31	3157	37.85	2.77	2.66	10.10	3154	42.96	2.48	2.65	9.99	3155	42.23	2.52
Avg.	2.56	10.0	3159	40.4	3.00	2.75	11.4	3153	43.7	2.58	2.73	11.2	3154	43.2	2.64

(1) NO_x from bag measurement
(2) HC instrument not working

TABLE C-17. EMISSION RATES FROM VEHICLE 3-17 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

Emission Rate, g/km

Test	Cold-Start					Hot-Start					Composite				
	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31721	2.28	6.91	1428	13.80	1.73	1.87	6.26	1322	15.22	1.22	1.93	6.35	1337	15.02	1.29
31722	2.01	6.86	1425	14.97	1.52	1.57	6.50	1334	15.79	1.38	1.63	6.55	1348	15.67	1.40
Avg.	2.15	6.89	1426	14.4	1.63	1.72	6.38	1328	15.5	1.30	1.78	6.45	1342	15.4	1.32

Emission Rate, g/kg fuel

Test	Cold-Start					Hot-Start					Composite				
	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31721	5.01	15.19	3140	30.34	3.80	4.44	14.88	3142	36.17	2.90	4.53	14.92	3142	35.34	3.03
31722	4.43	15.12	3142	33.00	3.35	3.70	15.32	3143	37.21	3.25	3.80	15.29	3143	36.61	3.27
Avg.	4.72	15.2	3141	31.7	3.58	4.07	15.1	3142	36.7	3.08	4.17	15.1	3142	36.0	3.15

(1) NO_x from bag measurement

TABLE C-18. EMISSION RATES FROM VEHICLE 3-18 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31821	1.82	4.78	1456	14.57	1.06	1.41	4.62	1420	16.48	0.80	1.47	4.64	1425	16.21	0.84
31822	2.13	4.67	1512	15.95	1.00	1.58	4.45	1445	17.06	0.83	1.66	4.48	1455	16.90	0.85
Avg.	1.98	4.73	1484	15.3	1.03	1.50	4.54	1432	16.8	0.82	1.57	4.56	1440	16.6	0.85

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31821	3.94	10.35	3151	31.53	2.29	3.13	10.26	3153	36.60	1.78	3.25	10.27	3153	35.87	1.85
31822	4.44	9.73	3149	33.22	2.08	3.45	9.71	3153	37.22	1.81	3.59	9.71	3152	36.65	1.85
Avg.	4.19	10.0	3150	32.4	2.19	3.29	9.99	3153	36.9	1.80	3.42	9.99	3152	36.3	1.85

(1) NO_x from bag measurement

TABLE C-19. EMISSION RATES FROM VEHICLE 3-19 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31921	2.52	6.39	1604	17.47	2.07	1.86	6.58	1418	16.92	1.32	1.95	6.55	1445	17.00	1.43
31923	2.47	6.24	1601	16.14	1.48	2.13	6.51	1538	17.46	1.17	2.18	6.47	1547	17.27	1.21
Avg.	2.50	6.32	1602	16.8	1.78	2.00	6.55	1478	17.2	1.25	2.06	6.51	1496	17.1	1.32

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
31921	4.94	12.52	3143	34.23	4.06	4.12	14.59	3144	37.52	2.93	4.24	14.30	3144	37.05	3.09
31922	4.85	12.26	3144	31.70	2.91	4.35	13.31	3144	35.69	2.39	4.42	13.16	3144	35.12	2.47
Avg.	4.90	12.4	3144	33.0	3.49	4.24	14.0	3144	36.6	2.66	4.33	13.7	3144	36.1	2.78

(1) NO_x from bag measurement

TABLE C-20. EMISSION RATES FROM VEHICLE 3-20 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-455-F (NO. 1 EMISSION TEST FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.
32031	1.89	43.45	1395	10.60	5.35	1.80	29.84	1222	9.98	3.86	1.81	31.78	1247	10.07	4.07
32032	1.90	45.82	1410	11.88	4.43	1.70	31.62	1190	9.95	2.93	1.73	33.65	1221	10.23	3.14
Avg.	1.90	44.6	1402	11.2	4.89	1.75	30.7	1206	9.97	3.40	1.77	32.7	1234	10.2	3.61

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.	HC	CO	CO_2	NO_x[1]	Part.
32031	4.07	93.62	3006	22.84	11.53	4.47	74.08	3034	24.78	9.58	4.41	76.87	3030	24.50	9.86
32032	4.04	97.43	2998	25.26	9.42	4.32	80.35	3024	25.29	7.45	4.28	82.79	3020	25.28	7.73
Avg.	4.06	95.5	3002	24.0	10.5	4.40	77.2	3029	25.0	8.52	4.35	79.8	3025	24.9	8.80

[1] NO_x from bag measurement

TABLE C-21. EMISSION RATES FROM VEHICLE 3-21 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-455-F (NO. 1 EMISSION TEST FUEL)

Test	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
32131	0.67	3.24	823	12.25	1.00	0.62	2.93	748	11.19	0.90	0.63	2.97	759	11.34	0.91
32132	0.80	3.19	806	11.61	1.07	0.72	2.77	731	10.49	0.99	0.73	2.83	742	10.65	1.00
Avg.	0.74	3.22	814	11.9	1.04	0.67	2.85	740	10.8	0.95	0.68	2.90	750	11.0	0.96

Test	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
32131	2.55	12.35	3137	46.69	3.81	2.60	12.29	3138	46.94	3.78	2.59	12.30	3138	46.90	3.78
32132	3.11	12.41	3136	45.18	4.16	3.09	11.89	3137	45.01	4.25	3.09	11.96	3137	45.04	4.24
Avg.	2.83	12.4	3136	45.9	3.99	2.85	12.1	3138	46.0	4.02	2.84	12.1	3138	46.0	4.01

(1) NO_x from bag measurement

TABLE C-22. EMISSION RATES FROM VEHICLE 3-22 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-455-F (NO. 1 EMISSION TEST FUEL)

	Emission Rate, g/km														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
32231	1.80	16.15	1430	19.42	2.05	1.67	10.31	1241	16.57	1.51	1.69	11.14	1268	16.98	1.59
32232	1.67	14.78	1419	17.91	2.11	1.66	10.91	1263	16.88	1.39	1.66	11.46	1285	17.03	1.49
Avg.	1.74	15.5	1424	18.7	2.08	1.67	10.6	1252	16.7	1.45	1.68	11.3	1277	17.0	1.54

	Emission Rate, g/kg fuel														
	Cold-Start					Hot-Start					Composite				
Test	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.	HC	CO	CO_2	NO_x (1)	Part.
32231	3.90	34.98	3097	42.08	4.44	4.19	25.84	3111	41.53	3.78	4.14	27.15	3109	41.61	3.88
32232	3.65	32.32	3103	39.16	4.61	4.09	26.86	3109	41.55	3.42	4.02	27.64	3108	41.21	3.59
Avg.	3.78	33.6	3100	40.6	4.53	4.14	26.4	3110	41.5	3.60	4.08	27.4	3108	41.4	3.74

(1) NO_x from bag measurement

TABLE C-23, EMISSION RATES FROM VEHICLE 3-23 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

Percent of GVW	Test	Emission Rate, g/km: Cold-Start HC	Cold-Start CO	Cold-Start CO_2	Cold-Start NO_x[a]	Cold-Start Part.	Hot-Start HC	Hot-Start CO	Hot-Start CO_2	Hot-Start NO_x[a]	Hot-Start Part.	Composite HC	Composite CO	Composite CO_2	Composite NO_x[a]	Composite Part.
61%	32325 R-1	3.42	4.45	1111	8.24	1.71	3.33	3.67	1000	8.45	1.11	3.34	3.78	1016	8.42	1.20
	32325 R-2	3.22	4.32	1094	8.18	1.42	3.33	3.71	978	8.34	1.22	3.31	3.80	995	8.32	1.25
	Avg.	3.32	4.39	1102	8.21	1.56	3.33	3.69	989	8.40	1.16	3.33	3.79	1006	8.37	1.22
70%	32322	3.28	4.33	1180	9.39	1.54	3.11	3.54	1026	9.23	1.12	3.13	3.65	1048	9.25	1.18
	32324	3.09	4.07	1128	8.70	1.38	3.22	3.68	1005	8.74	1.17	3.20	3.74	1023	8.73	1.20
	Avg.	3.18	4.20	1154	9.04	1.46	3.16	3.61	1016	8.99	1.14	3.16	3.70	1036	8.99	1.19
80%	32327 R-1	3.53	4.38	1170	9.24	1.70	3.42	3.82	1125	--[b]	1.21	3.44	3.90	1131	--[b]	1.28
	32327 R-2	3.32	4.67	1187	9.74	1.49	3.70	4.34	1073	10.55	1.31	3.65	4.39	1089	10.43	1.34
	Avg.	3.42	4.52	1178	9.49	1.60	3.56	4.08	1099	10.6[c]	1.26	3.54	4.15	1110	10.4[c]	1.31
93%	32326 R-1	3.28	4.96	1247	10.73	1.61	3.06	4.15	1117	11.15	1.24	3.09	4.27	1136	11.09	1.29
	32326 R-2	3.25	4.66	1232	10.39	1.53	3.18	4.04	1156	10.65	1.19	3.19	4.13	1167	10.61	1.24
	Avg.	3.27	4.81	1240	10.6	1.57	3.18	4.10	1136	10.9	1.22	3.14	4.20	1152	10.8	1.26

[a] NO_x from bag measurement
[b] No NO_x data
[c] Avg. is from test 32327 Run 2 only

TABLE C-24. FUEL SPECIFIC EMISSION RATES FROM VEHICLE 3-23 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

Percent of GVW	Test	Emission Rate, g/kg fuel														
		Cold-Start					Hot-Start					Composite				
		HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.
61%	32325 R-1	9.64	12.54	3130	23.22	4.82	10.42	11.48	3128	26.43	3.47	10.30	11.63	3128	25.97	3.66
	32325 R-2	9.21	12.36	3131	23.41	4.06	10.65	11.87	3128	26.67	3.90	10.45	11.94	3128	26.21	3.93
	Avg.	9.42	12.4	3130	23.3	4.44	10.5	11.7	3128	26.6	3.68	10.4	11.8	3128	26.1	3.80
70%	32322	8.71	11.49	3132	24.93	4.09	9.49	10.80	3131	28.17	3.42	9.38	10.90	3131	27.70	3.51
	32324	8.59	11.31	3134	24.17	3.83	10.03	11.46	3130	27.22	3.64	9.82	11.44	3130	26.78	3.67
	Avg.	8.65	11.4	3133	24.6	3.96	9.76	11.1	3130	27.7	3.53	9.60	11.2	3130	27.2	3.59
80%	32327 R-1	9.44	11.72	3129	24.71	4.55	9.52	10.63	3132	--[b]	3.37	9.51	10.79	3131	--[b]	3.54
	32327 R-2	8.76	12.32	3131	25.69	3.93	10.78	12.64	3126	30.73	3.83	10.49	12.60	3126	30.01	3.83
	Avg.	9.10	12.0	3130	25.2	4.24	10.15	11.6	3129	30.7[c]	3.60	10.0	11.7	3128	30.0[c]	3.68
93%	32326 R-1	8.24	12.47	3134	26.97	4.05	8.58	11.64	3133	31.27	3.48	8.53	11.76	3133	30.66	3.56
	32326 R-2	8.27	11.86	3134	26.43	3.89	8.62	10.96	3135	28.88	3.23	8.57	11.08	3135	28.53	3.32
	Avg.	8.26	12.2	3134	26.7	3.97	8.60	11.3	3134	30.1	3.36	8.55	11.4	3134	29.6	3.44

[a] NO_x from bag measurement
[b] No NO_x data
[c] Avg. is from test 32327 Run 2 only

TABLE C-25. EMISSION RATES FROM VEHICLE 3-24 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

			Emission Rate, g/km														
			Cold Start					Hot Start					Composite				
Percent of GVW	Horsepower[a]	Test Number	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.
55%	Standard	32424R-1	1.57	3.20	1513	14.31	1.14	1.75	3.18	1406	14.52	1.15	1.72	3.18	1421	14.49	1.15
	Standard	32424R-3	1.61	3.41	1514	14.88	1.14	1.72	3.56	1393	14.22	1.12	1.70	3.54	1410	14.31	1.12
		Avg.	1.59	3.31	1514	14.6	1.14	1.74	3.37	1400	14.4	1.14	1.71	3.36	1416	14.4	1.14
	Reduced	32424R-2 Hot 1	—[c]					1.67	3.18	1320	13.22	1.06	—[c]				
	Reduced	32424R-2 Hot 2	—[c]					1.62	3.34	1310	12.88	1.10	—[c]				
	Reduced	32424R-4 Hot 1	—[c]					1.71	3.29	1315	12.46	1.01	—[c]				
	Reduced	32424R-4 Hot 2	—[c]					1.65	2.84	1351	13.11	1.09	—[c]				
		Avg.						1.66	3.17	1324	12.9	1.07					
70%	Standard	32421R-1	1.53	4.45	1675	17.23	1.31	1.63	4.83	1591	18.09	1.47	1.62	4.78	1603	17.97	1.45
	Standard	32421R-2	1.64	4.29	1696	16.84	1.26	1.62	4.61	1602	17.17	1.24	1.62	4.56	1615	17.12	1.24
		Avg.	1.59	4.37	1686	17.0	1.29	1.63	4.72	1596	17.6	1.36	1.62	4.67	1609	17.6	1.35
	Reduced	32421R-3	1.75	4.34	1603	16.62	1.28	1.70	4.26	1525	16.50	1.10	1.71	4.27	1536	16.52	1.13
	Reduced	32421R-4	1.67	3.89	1608	16.15	1.18	1.65	3.99	1521	16.25	1.18	1.65	3.98	1533	16.24	1.18
		Avg.	1.71	4.12	1606	16.4	1.23	1.68	4.13	1523	16.4	1.14	1.68	4.13	1534	16.4	1.16
86%	Standard	32422R-1	1.66	4.96	1890	19.41	1.22	1.63	5.70	1780	19.56	1.19	1.63	5.59	1796	19.54	1.19
	Standard	32422R-3	1.78	5.36	1841	21.52	1.33	1.64	6.14	1739	19.74	1.32	1.66	5.02	1754	19.99	1.32
		Avg.	1.72	5.16	1866	20.5	1.28	1.64	5.92	1760	19.6	1.26	1.65	5.81	1775	19.8	1.26
	Reduced	32422R-2 Hot 1	—[c]					1.70	5.09	1576	16.82	1.06	—[c]				
	Reduced	32422R-2 Hot 2	—[c]					1.53	5.13	1589	16.81	1.06	—[c]				
	Reduced	32422R-4 Hot 1	—[c]					1.66	5.92	1610	18.03	1.16	—[c]				
	Reduced	32422R-4 Hot 2	—[c]					1.64	5.65	1610	17.64	1.17	—[c]				
		Avg.						1.63	5.45	1596	17.3	1.11					
97%	Standard	32423R-1	1.70	6.03	1956	21.68	1.44	1.62	7.42	1849	20.93	1.37	1.63	7.22	1864	21.04	1.38
	Standard	32423R-3	1.71	7.27	1907	21.82	1.55	1.67	8.14	1817	22.00	1.42	1.68	8.02	1830	21.97	1.44
		Avg.	1.71	6.65	1932	21.8	1.50	1.65	7.78	1833	21.5	1.40	1.66	7.62	1847	21.5	1.41
	Reduced	32423R-2 Hot 1	—[c]					1.61	6.84	1720	19.82	1.26	—[c]				
	Reduced	32423R-2 Hot 2	—[c]					1.61	6.79	1729	19.68	1.20	—[c]				
	Reduced	32423R-4 Hot 1	—[c]					1.66	7.02	1696	19.57	1.29	—[c]				
	Reduced	32423R-4 Hot 2	—[c]					1.74	7.80	1679	18.95	1.34	—[c]				
		Avg.						1.66	7.11	1706	19.5	1.27					

[a] Horsepower programmed into dynamometer
[b] NO_x from bag measurement
[c] No cold start at reduced horsepower

TABLE C-26. FUEL SPECIFIC EMISSION RATES FROM VEHICLE 3-24 (TESTED IN TASK 3) OPERATED OVER THE CHASSIS VERSION OF THE TRANSIENT CYCLE USING EM-528-F (PHILLIPS DF-2 REFERENCE FUEL)

			Emission Rate, g/kg fuel														
			Cold Start					Hot Start					Composite				
Percent of GVW	Horsepower[a]	Test Number	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.	HC	CO	CO_2	NO_x[b]	Part.
55%	Standard	32424R-1	3.28	6.68	3159	29.88	2.38	3.93	7.14	3156	32.59	2.58	3.84	7.07	3157	32.21	2.55
	Standard	32424R-3	3.36	7.11	3157	31.02	2.38	3.89	8.06	3153	32.19	2.54	3.82	7.92	3154	32.02	2.51
		Avg.	3.32	6.90	3158	30.4	2.38	3.91	7.60	3155	32.4	2.56	3.83	7.50	3156	32.1	2.53
	Reduced	32424R-2 Hot 1	—	—	—	—	—[c]	3.99	7.62	3156	31.61	2.54	—	—	—	—	—[c]
	Reduced	32424R-2 Hot 2	—	—	—	—	—[c]	3.90	8.04	3154	31.01	2.65	—	—	—	—	—[c]
	Reduced	32424R-4 Hot 1	—	—	—	—	—[c]	4.10	7.89	3154	29.88	2.42	—	—	—	—	—[c]
	Reduced	32424R-4 Hot 2	—	—	—	—	—[c]	3.86	6.64	3157	30.64	2.55	—	—	—	—	—[c]
		Avg.						3.96	7.55	3155	30.8	2.54					
70%	Standard	32421R-1	2.88	8.39	3156	32.47	2.47	3.23	9.58	3154	35.86	2.91	3.18	9.41	3154	35.38	2.85
	Standard	32421R-2	3.05	7.99	3158	31.36	2.35	3.19	9.08	3154	33.80	2.44	3.17	8.92	3155	33.46	2.43
		Avg.	2.97	8.19	3157	31.9	2.41	3.21	9.33	3154	34.8	2.68	3.18	9.17	3155	34.4	2.64
	Reduced	32421R-3	3.45	8.54	3156	32.72	2.52	3.52	8.81	3153	34.12	2.27	3.51	8.77	3154	33.92	2.31
	Reduced	32421R-4	3.28	7.64	3157	31.70	2.32	3.42	8.28	3155	33.71	2.45	3.40	8.19	3155	33.42	2.43
		Avg.	3.37	8.09	3157	32.2	2.42	3.47	8.55	3154	33.9	2.36	3.46	8.48	3155	33.67	2.37
86%	Standard	32422R-1	2.77	8.29	3157	32.43	2.04	2.89	10.10	3154	34.66	2.11	2.87	9.84	3155	34.34	2.10
	Standard	32422R-3	3.05	9.19	3156	36.89	2.28	2.97	11.13	3153	35.79	2.39	2.98	10.85	3153	35.95	2.38
		Avg.	2.91	8.74	3157	34.7	2.16	2.93	10.62	3154	35.2	2.25	2.93	10.35	3154	35.2	2.24
	Reduced	32422R-2 Hot 1	—	—	—	—	—[c]	3.50	10.18	3152	33.65	2.12	—	—	—	—	—[c]
	Reduced	32422R-2 Hot 2	—	—	—	—	—[c]	3.04	10.18	3154	31.96	2.10	—	—	—	—	—[c]
	Reduced	32422R-4 Hot 1	—	—	—	—	—[c]	3.25	11.59	3151	35.29	2.27	—	—	—	—	—[c]
	Reduced	32422R-4 Hot 2	—	—	—	—	—[c]	3.21	11.06	3152	34.54	2.20	—	—	—	—	—[c]
		Avg.						3.25	10.8	3152	33.9	2.20					
97%	Standard	32423R-1	2.74	4.73	3155	34.97	2.32	2.76	12.64	3151	35.66	2.33	2.76	12.23	3151	35.56	2.33
	Standard	32423R-3	2.83	12.01	3151	36.05	2.56	2.89	14.10	3148	38.12	2.46	2.88	13.80	3148	37.82	2.48
		Avg.	2.79	10.9	3153	85.5	2.44	2.83	13.37	3150	36.9	2.40	2.82	13.0	3150	36.7	2.41
	Reduced	32423R-2 Hot 1	—	—	—	—	—[c]	2.94	12.53	3150	36.30	2.31	—	—	—	—	—[c]
	Reduced	32423R-2 Hot 2	—	—	—	—	—[c]	2.93	12.38	3151	35.87	2.19	—	—	—	—	—[c]
	Reduced	32423R-4 Hot 1	—	—	—	—	—[c]	3.08	13.03	3149	36.33	2.40	—	—	—	—	—[c]
	Reduced	32423R-4 Hot 2	—	—	—	—	—[c]	3.26	14.61	3145	35.50	2.51	—	—	—	—	—[c]
		Avg.						3.05	13.1	3149	36.0	2.35					

[a]Horsepower programmed into dynamometer
[b]NO_x from bag measurement
[c]No cold start at reduced horsepower. (Reduced horsepower was 80 percent of standard)

APPENDIX D

SUMMARY OF EMISSION RATES FROM CHASSIS AND ENGINE TESTING

TABLE D-1. SUMMARY OF EMISSION RATES FROM CHASSIS AND ENGINE TESING

			Emission Rate, g/km														
			Cold Start					Hot Start					Composite				
Vehicle Number	Description	Emission Rate	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.
2-1	1982 Bus DD6V-71	chassis, g/km	1.86	28.0	1389	12.1	1.53	1.72	20.3	1244	10.6	1.24	1.74	21.4	1262	10.8	1.28
		chassis, g/kg fuel	4.11	61.5	3055	26.6	3.36	4.24	50.3	3073	26.4	3.06	4.23	51.9	3070	26.4	3.10
		engine, g/kg fuel	6.20	27.6	3103	22.5	2.40	7.43	19.3	3110	22.9	2.18	7.25	20.5	3109	22.8	2.21
		engine, g/hp-hr	1.67	7.46	838	6.12	0.65	1.83	4.75	767	5.64	0.54	1.81	5.14	778	5.71	0.55

			Cold Start					Hot Start					Composite				
			HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.
2-2	1980 Cummins Form. 350	chassis, g/km	2.96	6.26	1455	13.9	1.15	1.91	5.44	1362	14.4	0.94	2.06	5.56	1375	14.3	0.97
		chassis, g/kg fuel	6.37	13.5	3138	30.0	2.48	4.40	12.6	3146	33.2	2.16	4.69	12.7	3145	32.7	2.21
		engine, g/kg fuel	5.04	11.8	3147	32.9	2.25	4.89	11.4	3149	36.4	2.12	4.91	11.5	3149	35.9	2.14
		engine, g/hp-hr	0.99	2.32	619	6.48	0.44	0.91	2.12	585	6.76	0.39	0.92	2.15	590	6.72	0.40

[a] NO_x from bag measurement

TABLE D-1 (CONT'D). SUMMARY OF EMISSION RATES FROM CHASSIS AND ENGINE TESTING

			Emission Rate, g/km														
			Cold Start					Hot Start					Composite				
Vehicle Number	Description	Emission Rate	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.
2-3	1980 DD8V-92TA	chassis,g/km	1.81	2.57	1531	13.5	0.94	1.70	2.19	1406	13.4	0.86	1.72	2.24	1424	13.4	0.87
		chassis, g/kg fuel	3.73	5.30	3159	27.9	1.94	3.83	4.92	3160	30.1	1.93	3.81	4.97	3160	29.8	1.93
		engine, g/kg fuel	3.28	8.66	3159	30.1	2.41	2.88	9.64	3158	33.8	1.86	2.97	9.50	3158	33.2	1.94
		engine, g/hp-hr	0.69	1.82	664	6.32	0.51	0.58	1.95	640	6.80	0.38	0.60	1.93	643	6.74	0.40
			Cold Start					Hot Start					Composite				
			HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.
2-4	1979 IHC DT-466	chassis, g/km	1.30	3.28	1070	9.77	0.79	1.12	2.75	986	8.76	0.77	1.15	2.82	998	8.91	0.78
		chassis, g/kg fuel	3.83	9.65	3152	28.8	2.34	3.67	8.77	3154	28.0	2.53	3.69	8.89	3154	28.1	2.50
		engine, g/kg fuel	4.12	11.0	3150	30.6	2.38	3.55	9.21	3159	30.0	2.29	3.63	9.47	3158	30.1	2.30
		engine, g/hp-hr	0.94	2.52	721	7.00	0.54	0.78	2.04	698	6.63	0.50	0.81	2.10	702	6.68	0.51

[a]NO_x from bag measurement

TABLE D-1 (CONT'D). SUMMARY OF EMISSION RATES FROM CHASSIS AND ENGINE TESTING

			Emission Rate, g/km															
			Cold Start					Hot Start					Composite				
Vehicle Number	Description	Emission Rate	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.	HC	CO	CO_2	NO_x[a]	Part.
3-23[b,c]	1981 Cummins NTC-300	chassis, g/km	3.18	4.20	1154	9.04	1.46	3.16	3.61	1016	8.99	1.14	3.16	3.70	1036	8.99	1.19
		chassis, g/kg fuel	8.65	11.4	3133	24.6	3.96	9.76	11.1	3130	27.7	3.53	9.60	11.2	3130	27.2	3.59
		engine, g/kg fuel	8.08	14.0	3135	34.2	2.67	7.12	14.4	3136	38.5	2.37	7.26	14.4	3136	37.9	2.42
		engine, g/hp-hr	1.58	2.74	613	6.68	0.52	1.32	2.69	584	7.17	0.44	1.36	2.70	588	7.10	0.45
3-24[c]	1980 DD8V-92TA	chassis, g/km	1.59	4.37	1686	17.0	1.29	1.63	4.72	1596	17.6	1.36	1.62	4.67	1609	17.6	1.35
		chassis, g/kg fuel	2.97	8.19	3157	31.9	2.41	3.21	9.33	3154	34.8	2.68	3.18	9.17	3155	34.4	2.64
		engine, g/kg fuel	2.80	9.91	3158	34.4	1.94	2.69	13.8	3152	37.6	2.34	2.71	13.3	3153	37.2	2.28
		engine, g/hp-hr	0.57	2.04	649	7.08	0.40	0.52	2.71	617	7.36	0.46	0.53	2.61	621	7.33	0.45

[a] *NO_x from bag measurement*
[b] Vehicle 3-23 chassis tests were conducted at 80 percent of standard horsepower
[c] Chassis data from tests at 70% of GVW

APPENDIX E

SUMMARY OF ENGINE AND CHASSIS EMISSION RATES IN SEVERAL SETS OF UNITS

TABLE E-1. SUMMARY OF ENGINE AND CHASSIS TRANSIENT EMISSION RATES

Vehicle No.	Engine	Emission Rate	Cycle	Exhaust Emission HC	CO	CO_2	NO_x	Part.
2-1	DD 6V-71	g/km	chassis	1.74	21.39	1262	10.85	1.28
		g/km	engine[a]	2.08	5.92	893	6.56	0.63
		g/hp-hr	engine	1.81	5.41	778	5.71	0.55
		g/kg fuel	chassis	4.23	51.9	3070	26.4	3.10
		g/kg fuel	engine	7.25	20.5	3109	22.8	2.21
		g/min	chassis	0.87	10.71	628	5.41	0.64
		g/min	engine	1.06	3.06	458	3.36	0.33
2-2	Cummins Form 350	g/km	chassis	2.06	5.56	1375	14.31	0.97
		g/km	engine[a]	1.88	4.39	1206	13.74	0.82
		g/hp-hr	engine	0.92	2.15	590	6.72	0.40
		g/kg fuel	chassis	4.69	12.7	3145	32.7	2.21
		g/kg fuel	engine	4.83	11.3	3150	34.6	2.12
		g/min	chassis	1.01	2.73	672	6.99	0.48
		g/min	engine	0.97	2.26	618	7.02	0.43
2-3	DD 8V-92TA	g/km	chassis	1.72	2.24	1424	13.40	0.87
		g/km	engine[a]	1.34	4.33	1440	15.08	0.89
		g/hp-hr	engine	0.60	1.93	643	6.74	0.40
		g/kg fuel	chassis	3.81	4.97	3160	29.8	1.93
		g/kg fuel	engine	2.97	9.50	3158	33.2	1.94
		g/min	chassis	0.85	1.10	697	6.56	0.43
		g/min	engine	0.69	2.24	738	7.73	0.46
2-4	IHC DT-466B	g/km	chassis	1.15	2.82	998	8.91	0.78
		g/km	engine[a]	1.00	2.62	873	8.31	0.64
		g/hp-hr	engine	0.81	2.10	702	6.68	0.51
		g/kg fuel	chassis	3.69	8.89	3154	28.10	2.50
		g/kg fuel	engine	3.63	9.47	3158	30.07	2.30
		g/min	chassis	0.59	1.48	508	4.55	0.40
		g/min	engine	0.52	1.35	446	4.25	0.33
3-23	Cummins NTC-300[b,c]	g/km	chassis	3.16	3.70	1036	8.99	1.19
		g/km	engine[a]	2.80	5.55	1211	14.6	0.93
		g/hp-hr	engine	1.36	2.70	588	7.10	0.45
		g/kg fuel	chassis	9.60	11.2	3130	27.2	3.59
		g/kg fuel	engine	7.26	14.4	3136	37.9	2.42
		g/min	chassis	1.54	1.80	505	4.38	0.58
		g/min	engine	1.44	2.86	623	7.53	0.48
3-24	DD8V-92TA[c]	g/km	chassis	1.62	4.67	1609	17.6	1.35
		g/km	engine[a]	1.36	6.66	1583	18.7	1.14
		g/hp-hr	engine	0.53	2.61	621	7.33	0.45
		g/kg fuel	chassis	3.18	9.17	3155	34.4	2.64
		g/kg fuel	engine	2.71	13.3	3153	37.2	2.28
		g/min	chassis	0.77	2.23	768	8.38	0.64
		g/min	engine	0.70	3.43	815	9.61	0.59

[a] Assuming an equivalent vehicle distance of 10.3 km per Tim Cox of EPA-Ann Arbor, October 1979
[b] Vehicle 3-23 chassis tests were conducted at 80 percent of standard horsepower
[c] Data from chassis tests was measured at 70 percent of GVW

APPENDIX F

REGULATED AND PARTICULATE EMISSIONS RESULTS FROM BUSES OPERATED OVER THE NEW YORK BUS CYCLE

TABLE F-1. EMISSION RATES FROM BUSES OPERATED OVER THE NEW YORK BUS CYCLE USING FUEL EM-455-F

Vehicle Number	Test	Emission Rate, g/km					Fuel Specific Emission Rate, g/kg fuel				
		HC	CO	CO_2	NO_x [a]	Part.	HC	CO	CO_2	NO_x [a]	Part.
3-8	3831	2.33	77.79	1420	12.04	6.09	4.76	158.9	2900	24.59	12.44
	3832	2.18	81.39	1508	13.84	6.34	4.20	156.8	2904	26.66	12.21
	Avg.	2.26	79.6	1464	12.9	6.22	4.48	158	2902	25.6	12.3
3-9	3931	2.61	33.98	1455	16.99	2.13	5.45	70.90	3036	35.45	4.44
	3932	2.39	29.98	1459	16.59	1.94	5.00	62.70	3052	34.70	4.06
	Avg.	2.50	32.0	1457	16.8	2.04	5.23	66.8	3044	35.1	4.25
3-20	32031	1.57	61.38	1518	11.77	5.57	3.07	120.0	2966	23.00	10.89
	32032	1.99	65.86	1523	12.91	5.44	3.86	127.7	2953	25.03	10.55
	Avg.	1.78	63.6	1520	12.3	5.51	3.47	124	2960	24.0	10.7
3-21[b]	32131	0.60	2.67	915	15.12	0.79	2.06	9.17	3143	51.92	2.71
	32132	0.76	2.71	893	16.45	0.93	2.67	9.53	3142	57.85	3.27
	Avg.	0.68	2.69	904	15.8	0.86	2.37	9.35	3142	54.9	2.99
3-22	32231	2.29	16.80	1467	17.57	1.80	4.83	35.44	3094	37.06	3.80
	32232	2.46	17.18	1554	19.80	1.80	4.90	34.22	3095	39.44	3.59
	Avg.	2.38	17.0	1510	18.7	1.80	4.87	34.8	3094	38.2	3.69

[a] NO_x from bag measurement
[b] Vehicle 3-21 is a small bus powered by a lower horsepowered engine than the other buses