EPA-AA-EVRB-92-01

TECHNICAL REPORT

DEVELOPMENT OF CONVERSION FACTORS FOR HEAVY-DUTY BUS ENGINES G/BHP-HR TO G/MILE

by

MATTHEW KITCHEN

and

WILLIAM DAMICO

Engine and Vehicle Regulations Branch
Regulation Development and Support Division

July 27, 1992

NOTICE

Technical reports do not necessarily represent final EPA decisions or positions. They are intended to present technical analysis of issues using data which are currently available. The purpose in the release of such reports is to facilitate the exchange of technical information and to inform the public of technical developments which may form the basis for a final EPA decision, position, or regulatory action.

Engine and Vehicle Regulation Branch
Regulatory Development and Support Division
Office of Mobile Sources
Office of Air and Radiation
U.S. Environmental Protection Agency

ABSTRACT

This technical report calculates conversion factors to convert emission results from EPA's heavy-duty truck transient test (expressed in g/bhp-hr), to equivalent levels for various in-use bus applications (expressed in g/mile). Conversion factors are calculated by comparing emission results from a bus engine operated on the EPA heavy-duty truck transient test cycle and various bus specific chassis test cycles. Pollutant specific conversion factors are developed for inter-city, urban, and heavy urban bus applications.

1.0 Introduction

The Environmental Protection Agency (EPA) emissions testing and certification program for heavy-duty vehicles, unlike the EPA programs for light-duty vehicles, focuses on engines and exhaust systems rather than total vehicles. Consequently, standards for heavy-duty vehicles are written in terms of grams of emission per unit of work done, such as grams per brake-horsepower per hour (g/bhp-hr), rather than grams per mile (g/mi). This approach to regulating heavy-duty vehicles has several advantages in terms of setting and enforcing emissions standards. On the other hand, the g/bhp-hr values available for certified engines do not lend themselves to the calculation of emissions inventories, which are typically expressed in g/mi figures. In order to calculate emission inventories, the emission factors for heavy-duty engines need to be converted from units of g/bhp-hr to units of g/mi. Thus a bhp-hr/mi conversion factor methodology is necessary.

EPA has previously calculated bhp-hr/mi conversion factors (both for heavy-duty vehicles in general and for various sub-classes of heavy-duty vehicles) for use in estimating emissions inventories. These conversion factors were based on estimates of the average amount of work that must be expended by the engine to propel the vehicle one mile. However, the conversion factors for buses, most notably urban buses, did not accurately reflect the effects that different types of bus operations have on the relative levels of emissions of specific pollutants. In order to more accurately model the emissions from urban buses, improved conversion factors are needed to relate the g/bhp-hr results of the engine dynamometer test to the g/mi emission factors for various types of bus operation.

Pollutant specific conversion factors for urban buses can be calculated if emissions data from chassis tests of buses (given in g/mi) and from the engines which power these buses (given in g/bhp-hr) are available. These data would preferably be from a set of bus/engine pairs with the bus chassis tested over a variety of test cycles. During the past decade, a relatively small number of buses have been emissions tested using a variety of test cycles. EPA has collected data from the only two test programs which have run reliable chassis tests on buses and for which dynamometer results are also available. From these data, updated estimates of appropriate bhp-hr/mi conversion factors for buses are derived.

2.0 Background

Historically, conversion factors for heavy-duty vehicles have been generated by relating the total amount of work done over the engine test cycle to the work required on the road. This was done by comparing fuel consumption values and assumed that emissions per unit of work done were constant and independent of the specific vehicle duty cycle. Thus, when engines are tested for emissions purposes, the brake-specific fuel consumption (BSFC) is measured.* Using this information, along with the density of the fuel used in the emissions testing and the fuel economy of the vehicle in which the engine is being used, the bhp-hr/mi conversion factor for that vehicle can be calculated using the formula:

$$CF\left(\frac{bhp\text{-}hr}{mi}\right) = \frac{\rho\left(\frac{lb}{gal}\right)}{BSFC\left(\frac{lb}{Bhp\text{-}hr}\right) * FE\left(\frac{mi}{gal}\right)}$$

Where: CF = conversion factor
FE = fuel economy
BSFC = brake specific fuel consumption
ρ = fuel density

Using this procedure, as well as data for various weight classes of vehicles and fuel types, EPA produced a report in 1988 which calculated sub-class and fuel-type specific conversion factors for heavy-duty vehicles of model years ranging from 1962 to 2000.[1] This conversion factor was non-pollutant specific and was 3.241 bhp-hr/mile.

This approach provided reasonable estimates of average heavy-duty vehicle emissions. However, it failed to reflect the differences in emissions related to different vehicle operating cycles. Since urban buses generally operate in ways which are quite different from other heavy-duty vehicles, such as line haul trucks, it is desirable to develop conversion factors based on direct comparisons of g/bhp-hr engine test data with g/mi bus test data. Furthermore, since the vehicle operating cycle may well affect various pollutants differently, it is also desirable to do this on a pollutant-specific basis. In order to properly derive such conversion factors, data must be obtained from a vehicle tested using both a chassis dynamometer cycle simulating

---

* The brake specific fuel consumption of an engine is the average mass of fuel consumed per Bhp-hr of work performed by the engine.

the operations of an urban bus and from the engine alone when removed and tested over the engine dynamometer certification test. In the past, a scarcity of data of this type has limited the ability to calculate pollutant specific conversion factors. However, data obtained recently from Environment Canada have made such calculations possible for buses. These data along with previously existing chassis test data can be used to calculate sets of pollutant specific conversion factors for buses. The remainder of this report will present both the available data and the analysis made on these data.

3.0 Description of Test Cycles

Five different bus test cycles and one truck test cycle were used in the studies reviewed in this technical report. The truck cycle consists of the chassis test version of the EPA heavy-duty diesel transient engine test. The bus cycles are those known as the Central Business District test cycle, The New York Bus Composite test cycle, the EPA unfiltered bus test cycle, the EPA filtered bus test cycle, and the New York Bus test cycle. The origins, uses and ramifications of each test cycle are addressed below.

The truck chassis cycle is intended to represent the same vehicle operations as the EPA heavy-duty transient engine dynamometer test for heavy-duty diesel engines. This is the cycle which is used to certify bus engines to Federal emissions standards. The cycle is composed of three different driving patterns. These patterns are the "New York Non-Freeway" which lasts for 254 seconds and covers a distance of 0.53 miles at an average speed of 7.56 mph, the "Los Angeles Non-Freeway" which lasts for 285 seconds and covers a distance of 1.15 miles with an average speed of 14.55 mph, and the "Los Angeles Freeway" which lasts for 254 seconds and covers 3.33 miles at an average speed of 44.94 mph. The New York Non-Freeway segment is run both at the beginning and end of this cycle, and the LA patterns are each run once in between.

The EPA filtered and unfiltered bus cycles were derived from the bus data in the same data collection program (known as CAPE21) that was used to design the heavy-duty certification test procedure. The unfiltered cycle is 1191 seconds in duration with an average speed of 8.77 mph and a total distance covered of 2.9 miles. This cycle is intended to represent a composite of the different types of bus operations. Consequently it has both a segment which represents low speed stop and go driving and a segment which represents higher but constantly varying speeds. One characteristic of this cycle is that it contains small, closely spaced, rapid changes in vehicle speeds. Some users of this cycle believe that such high frequency changes are probably not often seen in actual driving conditions. Therefore, a special version of this test cycle with the high frequency speed changes smoothed out has also been used. This test cycle is referred to as the EPA filtered cycle.

The Central Business District cycle (CBD), as its name implies, attempts to simulate driving in a heavily built up urban environment. The CBD test cycle is 600 seconds in duration with an average speed of 12.37 mph over a distance of 2.06 miles. The cycle consists of fifteen segments of equal length, wherein the bus accelerates from idle to 20 mph, holds at that speed for 20 seconds, and then decelerates back down to idle. This cycle is a simplified simulation of urban bus operation on a fixed route with fairly frequent, equidistant stops. The CBD test cycle is part of the Advanced Bus Design cycle created by the Department of Transportation and the Urban Mass Transit Association as part of the specifications for assessing bus performance.

The New York Bus Composite cycle (NYBC) is essentially a "compressed" version of the EPA unfiltered bus test cycle. It is 1029 seconds in duration with an average speed of 8.77 mph over a distance of 2.51 miles. The first part of the cycle simulates non-freeway driving, with abundant idle time. The second part of the cycle simulates freeway driving of a highly variable transient nature.

The final cycle used in this study is the New York Bus (NYB) cycle. This bus cycle attempts to simulate some of the toughest bus driving conditions which exist in the United States today. Data for this cycle was collected from a mid-town Manhattan route in New York City. The cycle consists of very rapid accelerations to speeds ranging from 15 to 50 mph and then rapid decelerations to idle. The bus sits at idle for long periods of time before it accelerates rapidly again. Thus, rapid stop and go traffic with long passenger transfer times are simulated.

In summary, these cycles thoroughly characterize the range of expected bus operation. The CBD, EPA filtered, EPA unfiltered and New York Composite cycles approximate the operation of the average urban bus. The Heavy-Duty Transient Chassis cycle represents the lightest duty a bus would be expected to be operated over, such as travelling from city to city, while the New York Bus cycle represents the heaviest duty a bus would be expected to encounter, such as transit operations in a heavily built-up urban inner city area (see Table 3-1).

TABLE 3-1 SUMMARY OF BUS CYCLES

BUS CYCLE	TIME (seconds)	DISTANCE TRAVELLED (miles)	AVG SPEED (mph)
EPA Truck	1047	5.54	18.52
EPA Unfiltered	1191	2.90	8.77
CBD	600	2.06	12.37
NYBC	1029	2.51	8.77
NYB	600	0.65	3.89

CBD= Central Business District, NYBC= New York Bus Composite Cycle, NYB= New York Bus Cycle

4.0 Test Programs

Based on a review of available test data, data from two test programs are used for the analysis conducted in this technical report. These test programs are the circa 1984 Southwest Research Institute (SwRI) chassis testing, and 1990 work at the Vehicle Emissions Testing Laboratory of Environment Canada. Results from these tests contain chassis test data on buses which have also had their engines emissions tested on an engine dynamometer. These two reports will serve as the sources of data for deriving the sets of pollutant specific conversion factors. (A summary of these two test programs is included in Table 4-1.) Results from other test programs which involved chassis testing on bus cycles are summarized in Appendix A. These results are included for reference purposes only as their lack of correlation to engine test results precludes their use in calculating conversion factors.

4.1 Southwest Research Institute

The Southwest Research Institute testing used in this report was conducted in the mid-1980's using a set of buses from San Antonio. The San Antonio buses were tested as part of a program to evaluate the then proposed heavy-duty transient test cycle. Four of the San Antonio buses were powered by 1980 Detroit Diesel Corporation six-cylinder naturally aspirated engines (DDC 6V-71N) while a fifth bus was equipped with a 1978 Detroit Diesel Corporation eight-cylinder naturally aspirated engine (DDC 8V-71N). All five buses were tested using the chassis version of the heavy-duty transient test cycle (the truck chassis cycle). Four of the buses were also tested using the EPA unfiltered bus test cycle. The engine of the remaining bus, one of the 1980 DDC

6V-71N engines, was removed from the bus and tested using the engine dynamometer test procedure. The results from these tests were published in a report in October of 1984.[2] Appendix B contains vehicle descriptions and emissions data from all the buses tested at SwRI during this test program.

Data collected included hydrocarbon (HC), carbon monoxide (CO), oxides of nitrogen (NOx) and particulate matter (PM) emissions. Unfortunately, the Southwest Research Institute testing did not include transient engine dynamometer testing and chassis testing on the same vehicle and engine pair. Had it done so, a direct g/BHP-hr to g/mile pollutant specific conversion factor set could have been constructed for the EPA unfiltered bus chassis cycle using data from a single bus-engine pair. It is useful, however, to indirectly construct a g/bhp-hr to g/mile conversion factor set, using the data from several bus tests, keeping in mind that the reliability of these conversion factors is reduced somewhat.

4.2 Environment Canada

The Vehicle Emission Testing Laboratory (VETL) of Environment Canada is a relatively new facility. However, during the short period since testing began at this facility, several buses have been tested. This facility is equipped to run only chassis dynamometer cycles. In one program, two passenger buses with Orion 45 cabs and Cummins L10 engines were tested at the VETL.

The data from the Orion 45 passenger buses were the result of a joint project between Environment Canada's Mobile Source Emissions Division (MSED) and Ontario Bus Industries Inc. The goal of this project was to characterize g/mi emissions from two new diesel-fueled urban buses. Three bus cycles were used during this program: the CBD, New York Bus Cycle, and the NYBC cycle. A chassis version of the EPA truck heavy-duty transient test was also utilized. Fortunately, the two Cummins L10 engines used in these buses had been tested prior to installation using the engine dynamometer test cycle at SwRI as part of a production engine emissions audit performed by Cummins. The Cummins Engine Company agreed to supply the emissions results from these two engines. Therefore, chassis versus engine results, as well as the effects of different operating parameters investigated in this testing, can all be examined using the data from these tests. This data is presented in Appendix C.[3]

The data from the Vehicle Emissions Testing Laboratory of Environment Canada included HC, CO, Nox, PM, aldehydes, methane, and volatile organic compounds (VOC) emissions, and was provided for two Cummins L10 equipped buses. For the purposes of this report we will concentrate on the regulated emissions HC, CO, Nox and PM. Since the engines had been dynamometer tested at SwRI as part of a production engine emissions audit performed by Cummins, chassis versus engine results, as well as the effects of different operating parameters investigated in this testing, can all be examined using the data from these tests. Each bus was tested at least twice with different combinations of fuel, inertia loadings and horsepower ratings. For the purposes of this report, the data which most closely approximated EPA heavy-duty test conditions was used.

TABLE 4-1 SUMMARY OF TEST PROGRAMS CITED

TEST PROGRAM	BUSES TESTED	BUS CYCLES
SWRI	3 1980 DDC 6V-71N	EPA HD Transient (chassis) EPA Unfiltered (chassis)
	1 1980 DDC 6V-71N	EPA HD Transient (chassis) EPA Engine Dynamometer
	1 1978 DDC 8V-71N	EPA HD Transient (chassis) EPA Unfiltered (chassis)
	2 1983 DDC 6V-92TA	EPA HD Transient (chassis) EPA Unfiltered (chassis) EPA Filtered (chassis) CBD (chassis)
	1 1982 DDC 6V-92TA	EPA HD Transient (chassis) EPA Unfiltered (chassis) EPA Filtered (chassis)
ENV CANADA	2 Cummins L10	EPA HD Transient (chassis) CBD (chassis) NYBC (chassis) NYB (chassis)

5.0 Methodology and Results

Where the emissions data are available from both the engine and chassis tests of the same bus, the pollutant specific bhp-hr/mi conversion factors can be directly calculated for that bus and the chassis cycle used merely by dividing the chassis emissions results by the engine emissions results. In order to construct a set of conversion factors for a full range of buses currently operating, test results would be needed for two-stroke and four-stroke bus engines both prior to the advent of particulate emissions control standards and after particulate emissions control standards. However, data for only pre-control two-stroke and post-control four-stroke engines are available.

(EPA started regulating bus PM emissions in 1988, therefore pre-control refers to pre-1988 bus engines and post control refers to 1988 and later bus engines.)

The data from the 1984 study at SwRI provides directly comparable engine and chassis emissions information for one bus equipped with a two-stroke 1980 DDC 6V-71 engine which was tested over the transient engine dynamometer test cycle and the truck chassis test cycle (labeled SwRI in table 5-1). The Canadian data provides engine and chassis data for two four-stroke buses equipped with 1990 Cummins L-10 engines (labeled 30293 and 30295 in table 5-1). The bhp-hr/mi conversion factors for these test sequences are presented in Table 5-1. The actual certification test results for these two engines are presented in appendix C. [4]

TABLE 5-1 Pollutant Specific Conversion Factors Calculated Directly

Bus	Chassis Cycle	Fuel Economy (mpg)	Pollutant Specific Conversion Factors (bhp-hr/mile)			
			HC	CO	Nox	PM
SWRI	HDT	N/A	1.68	4.62	2.86	3.17
30295	HDT	4.02	1.74	4.05	3.86	3.17
30293	HDT	4.06	1.37	4.55	3.20	3.44
30295	CBD	2.93	2.09	8.45	5.34	6.61
30293	CBD	3.33	2.04	9.23	3.89	6.05
30295	NYB	1.60	5.65	24.00	7.19	18.99
30293	NYB	1.69	5.22	27.14	6.73	17.29
30295	NYBC	3.11	2.15	12.37	4.44	11.98
30293	NYBC	3.46	2.93	12.21	3.52	7.07

HDT=Heavy-Duty Transient, CBD=Central Business District
NYB=New York Bus, NYBC=New York Bus Composite

In addition to the one bus which was tested on the transient engine dynamometer test cycle and truck chassis test cycle during the 1984 study performed by SwRI, four other buses powered with 1978 and 1980 DDC engines were tested using both the truck chassis test cycle and the EPA unfiltered bus cycle. In all tests, fuel consumption was measured, making it possible to report the emission results in units of g/kg of the fuel consumed, as well as g/mi. Since the one bus from which the engine was removed and tested was not operated over a bus cycle, it is not possible to directly convert from g/bhp-hr to g/mi for a bus cycle. However, this set of conversion factors could be calculated by chaining together the engine and chassis emissions data for the one bus for which engine data is available with the chassis data for both the truck and bus chassis cycles for the remainder of the buses. This is done by multiplying the bhp-hr/mi emission conversion factor for the bus tested on both cycles (i.e., ratio of engine dynamometer to truck chassis cycle emissions) by the ratio of the bus chassis cycle to truck chassis cycle emissions results for the buses tested on both cycles. Slightly different results are obtained depending on whether the ratio of the g/mi data is used or the ratio of the g/kg data. The conversion factors calculated using these pollutant specific conversion factors are presented in Table 5-2. The methodology of chaining together emission factors is presented in Appendix D.

TABLE 5-2 Conversion Factors Calculated Using SwRI Data

Chassis Cycle	Pollutant Specific Conversion Factors (bhp-hr/mi)			
	HC	CO	Nox	PM
EPA Unfiltered	2.21	6.17	3.40	4.37

As can be seen from Table 5-1, the 1980 bus with a two-stroke engine yielded approximately the same truck chassis test cycle conversion factors as the two buses equipped with 1990 four-stroke engines. Although the limited data supports only tentative conclusions, it does appear that conversion factors are not a strong function of design technology. However, they clearly are heavily dependent on the chassis cycle used and the pollutant of concern, as can be seen in Table 5-1.

In comparing the conversion factors calculated from the Environment Canada data to the conversion factors calculated from the SwRI data, (if. engine dynamometer to New York bus composite chassis cycle as contained in Table 5-1 versus engine dynamometer to EPA unfiltered chassis cycle as contained in Table 5-2), it may be seen that the conversion factors for CO and PM from the SwRI study do not match those from the Canadian study. (This comparison is appropriate because the New York composite and EPA unfiltered bus cycle are similar.) This discrepancy is believed to be mostly attributable to the aspiration techniques and strategy connected with the efforts to comply with the particulate regulations. These strategies are only fully effective at high engine speeds, which are achieved during the engine dynamometer cycle but are not seen very often during the New York composite or EPA unfiltered bus cycles. Therefore, this discrepancy may indicate a difference in the level of control of the emissions of CO and particulates between truck type operation and bus type operations.

6.0 Calculation of Conversion Factors

Based on the above analysis, it is possible to construct conversion factors applicable to buses over a range of in-use driving patterns. The basic premise is that the data from the two Cummins L-10 four-stroke bus engines tested at the Canadian laboratory will provide conversion factors representative of all bus engines based on the above-discussed good correlation with the SwRI data. It is immediately evident from Table 5-1 that the g/mi emissions factors are strongly influenced by the type of operations of the vehicle. Since urban buses experience a wide variety of operating practices and conditions, it is evident that they will exhibit a range of g/mi emission factors. Therefore, a range of conversion factors will be developed.

The buses tested in the Canadian program were tested using chassis cycles which represented a range of operating duty cycles. One method of gauging the severity of the duty of an operating cycle is to look at the fuel consumption of the vehicles when tested on that cycle. In general, the lower the fuel economy, the more severe (i.e., stop and go with lots of acceleration and deceleration) the operation of the cycle. Referring back to the fuel consumption rates of Table 5-1 for the buses operated over the four chassis cycles at the Canadian laboratory, it can be seen that the Heavy-Duty Truck chassis cycle has the lightest duty of the four cycles with an average fuel economy of 4.04 miles per gallon while the New York Bus cycle has the heaviest duty with an average fuel economy of 1.65 miles per gallon. The CBD and New York composite cycles are more in the mid-range of duty factors and fuel consumption rates with average fuel economies of 3.13 miles per gallon and 3.29 miles per gallon respectively. Since these are both close to the urban bus average fuel economy of approximately 3.3 miles per gallon [5], the average of these two middle duty cycles provides reasonable estimates of conversion factors for average bus operations. The New York City cycle provides the maximum duty conversion factor for bus operation. This cycle is representative of driving in heavily congested inner city areas. The truck chassis cycle provides the minimum duty conversion factor. This cycle would be more representative of inter-city bus routes. The range of conversion factors obtained from the Canadian study is presented in Table 6-1.

TABLE 6-1 RANGE OF BUS CONVERSION FACTORS (bhp-hr/mile)

Operating Level	HC	CO	NOx	PM
Inter-city	1.6	4.3	3.5	3.3
Urban	2.3	10.6	4.3	7.9
Heavy Urban	5.4	25.6	7.0	18.1

7.0 CONCLUSION

Table 6-1 contains the pollutant-specific bus conversion factors for inter-city, urban, and heavy urban bus operating levels. It should be noted that these factors are based on very limited data. In order to develop more statistically reliable conversion factors, further testing needs to be conducted. Data which allow direct comparisons between identical engines at equivalent mileage accumulation levels in terms of engine tested g/bhp-hr and chassis tested g/mile, need to be developed. Further testing in the area of conversion factor cross-applicability to both two and four stroke engines also needs to be developed. Using the methodology developed in this report and with new data from further testing, more refined g/bhp-hr to g/mile conversion factors for a variety of bus operating conditions could be developed.

REFERENCES

1. "Heavy-Duty Vehicle Emission Conversion Factors II 1962-2000", Standards Development and Support Branch, Emission Control Technology Division, Office of Mobile Sources, Office of Air and Radiation, EPA, EPA-AA-SDSB-89-01, October 1988.

2. "Characterization of Heavy-Duty Motor Vehicle Emissions Under Transient Driving Conditions," Mary Ann Warner-Selph and Harry E. Dietzmann, Southwest Research Institute, EPA report number EPA/600/3-84/104, October 1984 (NTIS number PB85-124154/REB).

3. "Evaluation of Regulated Exhaust Emissions from Urban Buses," Greg Rideout, Vehicle Emissions Testing Laboratory, Environment Canada, June 1990.

4. Cummins Engine Company, Inc. SwRI Letter Report 08-3952, January 7, 1991.

5. "1989 Transit Operating and Financial Statistics," American Public Transit Association.

APPENDIX A
SUPPLEMENTAL INFORMATION

Southwest Research Institute

In addition to the five buses from San Antonio tested by the Southwest Research Institute for the study published in 1984, three other buses from Houston were also tested in the same time frame. Two of these buses were equipped with 1983 model Detroit Diesel Corporation six-cylinder turbocharged engines (DDC 6V-92TA) while the third bus had a 1982 model DDC 6V-92TA engine. In addition to the truck chassis cycle and the unfiltered EPA bus chassis cycle, two additional chassis cycles were run on these buses. All three buses were tested using a version of the EPA bus chassis cycle with the high frequency transients filtered out (EPA filtered). In addition, two of the buses were tested using the Central Business District test cycle. This data is in Table A-1 below.

Chevron Research Company Data

The Chevron Research Company in Richmond, California has been performing chassis tests on urban buses since early in 1988. The purposes of this series of tests are mainly to test alternative fuels and fuel formulations as well as to test unproven bus technologies. However, conventional diesel buses were also tested in the program to use as comparisons/controls. In the first set of tests, a GMC coach with a 1982 model DDC 6V-92 engine was tested over the CBD and unfiltered EPA bus chassis cycles as well as some steady-state cycles.[1] The test engine used in this bus had accumulated 95,700 miles.

As part of an as yet unfinished and unpublished set of tests, Chevron has also tested a late model diesel bus from the Southern California Regional Transit District fleet. This bus is equipped with a recent model 1989 Detroit Diesel 6V-92TA engine and was a relatively low mileage bus with only 34,000 miles. The inertial and road load simulated were not explicitly stated but appear to have been calculated using the standard techniques for buses. The only cycle used in the testing so far is the CBD cycle. The average emissions results from three runs of the test cycle using a blend of two commercially available diesel fuels from southern California have been made available for publication. This data is contained in table A-2 below.

New York City Transit Authority

The New York City Transit Authority has performed testing on buses as far back as 1980. For purposes of this report, only a small set of data from New York's ongoing particulate trap study is being included. This study, which is intended to perform developmental and comparative testing of particulate trap systems for buses in actual revenue service, has been ongoing since May of 1989. The data used in this report are taken from one bus tested in August of 1990. This bus consisted of a GMC RTS model coach with a 1989 DDC 6V-92TA engine, a three-speed automatic transmission and a gross vehicle weight rating of 36,900 pounds. At the time of the testing, the bus had accumulated 83,921 miles. During the testing, #1 diesel fuel was used. Although this bus was one of the buses used for trap developmental testing, the data included here were collected from tests performed with the trap system removed and a stock muffler put in its place. Three different transient cycles were performed consisting of the CBD cycle, the New York Bus cycle and the NYBC cycle. Unfortunately the dynamometers available to the New York City Transit Authority could not simulate the full road load of the bus chassis so the test results had to be adjusted for this fact, making the results somewhat questionable. This data is contained in table A-3 below.

1.24 Environment Canada

Another VETL program did comparative testing using four diesel buses and three light-duty vehicles. The results of the VETL comparative testing between buses and light-duty vehicles were published in June of 1990. Three of the buses tested were typical of the types of urban buses common in the United States having testing inertia weights of 28,200 pounds and using DDC 1982 6V-71 N, DDC 1989 6V-92 TA and 1990 DDC 6V-92 TA engines. The fourth bus was somewhat larger than the typical U.S. urban bus with a testing weight of 35,000 pounds and a 1984 Cummins NHHTC-300 engine. The bus with the 1982 Detroit Diesel engine was tested both before and after routine maintenance. The only transient cycle used during the testing was the EPA truck chassis cycle. The buses were operated using commercial #1 diesel fuel.

TABLE A-1: SwRI CHASSIS TESTING RESULTS

BUSES	CYCLE	EMISSION FACTORS (G/MI)				
		MPG	HC	CO	NOx	PM
HOUSTON-1 6V-92TA 1983 55,000 miles	EPA Truck	4.9	1.2	11.7	24.0	2.6
	EPA Unfilt	3.8	2.1	38.4	32.2	5.5
	EPA Filter	4.6	2.4	5.1	30.5	1.7
HOUSTON-2 6V-92TA 1983 100,000 miles	EPA Truck	5.2	1.8	5.8	19.2	1.6
	EPA Unfilt	4.25	2.87	1.04 10.4	26.7	2.1
	EPA Filter	4.8	3.1	5.1	24.9	1.4
	CBD	3.7	2.8	15.9	29.6	2.8
HOUSTON-3 6V-92TA 1982 139,000 miles	EPA Truck	4.9	2.7	12.6	15.7	3.9
	EPA Unfilt	3.9	4.7	25.7	21.9	6.3
	EPA Filter	4.7	5.1	10.0	20.9	3.4
	CBD	3.5	4.1	28.6	23.3	6.3

EPA Truck= EPA Heavy-Duty Transient Cycle
EPA Unfilt= EPA Unfiltered Cycle
EPA Filter= EPA Filtered Cycle
CBD= Central Business District Cycle

TABLE A-2: CHEVRON TESTING RESULTS

BUSES	CYCLE	EMISSION FACTORS (G/MI)				
		MPG	HC	CO	NOx	PM
DDC 6V-92TA 1982 34,000 *	CBD	3.9	6.9	59.0	30.0	5.6
	Unfilt	4.8	4.0	51.0	28.0	2.4
	CBD	NA	3.3	31.8	34.0	5.4
	CBD	4.2	6.4	56.0	28.0	5.3
	CBD	4.0	6.6	55.9	28.1	5.3
	Unfilt	4.0	5.0	59.8	33.4	2.4
	Unfilt	5.1	3.7	47.4	26.2	2.3
	Unfilt	4.9	3.9	49.2	26.5	2.4

CBD= Central Business District   Unfilt= EPA Unfiltered
* Average of three tests.

TABLE A-3: NEW YORK CITY TESTING RESULTS

BUSES	CYCLE	EMISSION FACTORS (G/MI)				
		MPG	HC	CO	NOx	PM
DDC 6V-92TA 1989 83,921	CBD	4.1	2.8	5.3	26.3	1.0
	NYB	1.7	8.5	11.9	77.5	2.1
	NYBC	3.6	3.8	6.0	32.1	1.1
	NYBC	3.6	3.9	6.0	32.5	1.1

CBD= Central Business District   NYB= New York Bus
NYBC= New York Bus Composite

APPENDIX B

SwRI CHASSIS TESTING RESULTS

BUSES	CYCLE	EMISSION FACTORS (G/MI)				
		MPG	HC	CO	Nox	PM
SAN ANTONIO-1 6V-71N 1980 164,000 miles	EPA Truck	4.7	2.5	86.3	16.4	7.1
	EPA Unfilt	3.8	3.6	128.8	20.8	10.0
SAN ANTONIO-2 6V-71N 1980 182,000 miles	EPA Truck	4.9	2.9	28.8	22.2	2.3
	EPA Unfilt	4.0	4.0	51.5	27.0	3.3
SAN ANTONIO-3 6V-71N 1980 137,000 miles	EPA Truck	4.7	2.9	52.6	16.4	5.8
	EPA Unfilt	3.7	2.9	102.3	19.8	8.9
SAN ANTONIO-4 8V-71N 1978 247,000 miles	EPA Truck	4.6	2.7	18.2	27.4	2.5
	EPA Unfilt	3.9	3.8	27.4	30.1	2.9
SAN ANTONIO-5 6V-71N 1980 95,000 miles	EPA Truck	NA	2.8	34.4	17.4	2.1
	Engine (Dyno) g/bhp-hr	NA	1.7	7.5	6.1	0.7

EPA Truck= EPA Heavy-Duty Transient Cycle, EPA Unfilt= EPA Unfiltered Cycle,
EPA Filter= EPA Filtered Cycle
CBD= Central Business District Cycle

Testing Dec 1990 [illegible]
Aged engine
mileage 20,000

APPENDIX C

ENVIRONMENT CANADA TESTING RESULTS

BUS	CYCLE	FUEL CONSUMPTION (L/100 KM)	EMISSIONS (G/MI)			
			THC	CO	Nox	PM
Cummins L10 30295	EPA Truck-C	76.7	1.3	10.8	19.3	1.9
	EPA Truck-H	70.3	1.13	12.8	19.9	1.5
	CBD	96.6	1.4	26.8	27.6	3.1
	NYB	176.9	3.7	76.1	37.2	8.8
	NYBC	90.9	1.4	39.2	23.0	5.6
Cummins L10 30293	EPA Truck-C	69.4	1.1	12.3	16.1	2.1
	EPA Truck-H	63.7	1.0	13.7	16.6	1.7
	CBD	84.8	1.5	27.9	20.3	3.0
	NYB	81.5	2.1	36.9	18.3	3.5
	NYBC	167.2	3.8	82.0	35.0	8.5

EPA Truck-C= EPA Heavy-Duty Transient Cycle Cold Start
EPA Truck-H= EPA Heavy-Duty Transient Cycle Hot Start
CBD= Central Business District Cycle
NYB= New York Bus Cycle
NYBC= New York Bus Composite Cycle

SwRI DYNAMOMETER RESULTS (g/bhp-hr)

Bus Number	HC	CO	NOx	PM
30295	0.65	3.17	5.17	0.465
30293	0,73	3.02	5.20	0.491

CALCULATION OF BUS CONVERSION FACTORS

		Bus #30295 (4s)			Bus #30293 (4s)		
Bus Cycle	Pollutant Category	Dyno Test Results (SwRI)	Chassis Test Results (Ontario)	bhp-hr/ mile	Dyno Test Results (SwRI)	Chassis Test Results (Ontario)	bhp-hr/ mile
Heavy-duty Transient Cycle	HC CO NOx PM	0.65 3.17 5.17 0.465	1.13 12.84 19.94 1.475	1.74 4.05 3.86 3.17	0.73 3.02 5.2 0.491	1 13.74 16.62 1.69	1.37 4.58 3.20 3.44
Central Business District	HC CO NOx PM	0.65 3.17 5.17 0.486	1.38 28.8 27.59 3.075	2.09 8.45 5.34 8.61	0.73 3.02 5.2 0.491	1.49 27.86 20.25 2.97	2.04 9.23 3.89 6.05
New York Bus Cycle	HC CO NOx PM	0.65 3.17 5.17 0.486	3.67 78.08 37.16 8.83	5.65 24.00 7.19 18.90	0.73 3.02 5.2 0.491	3.81 81.95 35 8.49	5.22 27.14 8.73 17.29
New York Composite Cycle	HC CO NOx PM	0.65 3.17 5.17 0.465	1.4 39.21 22.96 5.57	2.15 12.37 4.44 11.96	0.73 3.02 5.2 0.491	2.14 38.87 18.31 3.47	2.93 12.21 3.52 7.07

APPENDIX D

CHAINED EMISSION FACTOR DATA (SwRI)

		Emissions				Units	Bus/Truck chassis			
engine	cycle	HC	CO	Nox	PM		HC	CO	NOx	PM
1982 6V-71N	EPA Truck	2.8	34.4	17.4	2.0	g/mi	1.7	4.6	2.9	3.2
	Engine	3.4	9.5	10.6	1.0	g/mi *	0.66	0.66	0.66	0.66
	EPA Truck	4.2	51.9	26.4	3.1	g/kg	2.5	7.0	4.3	4.8
	Engine	1.7	7.5	6.1	0.7	g/Bhp-hr				
1980 6V-71N	EPA Truck	2.5	86.3	16.4	7.1	g/mi				
	EPA Bus	3.6	9.7	20.8	10.0	g/mi	1.5	0 .1	1.3	1.4
	EPA Truck	3.9	132	25.2	10.9	g/kg				
	EPA Bus	4.5	158	25.6	12.3	g/kg	1.2	1.2	1.0	1.1
1980 6V-71N	EPA Truck	2.9	28.8	22.2	2.3	g/mi				
	EPA Bus	4.0	51.5	27.0	3.3	g/mi	1.4	1.8	1.2	1.4
	EPA Truck	4.7	45.8	35.4	3.7	g/kg				
	EPA Bus	5.2	66.8	35.1	4.3	g/kg	1.1	1.5	1.0	1.2
1980 6V-71N	EPA Truck	2.6	52.6	16.4	5.8	g/mi				
	EPA Bus	2.9	102.4	19.8	8.9	g/mi	1.0	1.9	1.2	1.5
	EPA Truck	4.4	79.8	24.9	8.8	g/kg				
	EPA Bus	3.5	124	24	10.7	g/kg	0 08	1.6	1.0	1.2
1980 8V-71N	EPA Truck	2.7	18.2	27.4	2.5	g/mi				
	EPA Bus	3.8	27.4	30.1	2.9	g/mi	1.4	1.5	1.1	1.2
	EPA Truck	4.1	27.4	41.4	3.7	g/kg				
	EPA Bus	4.9	34.8	38.2	3.7	g/kg	1.2	1.3	.9	1.0

CHAINED EMISSION DATA CONVERSION FACTOR CALCULATION

BHP-HR/MILE CONVERSION FACTORS

BASIS	HC	CO	NOx	PM
g/mi	2.21	6.17	3.40	4.37
g/kg	1.79	6.32	2.77	3.55

EQUATION D-2
CHAINED CONVERSION FACTOR CALCULATION

$$CF = A * \frac{\sum_{1}^{N} (B/T)_N}{N}$$

Where:
A is the Bhp-hr/mile engine dynamometer to truck chassis cycle conversion factor of the SwRI bus tested.
B is the bus chassis cycle emission value.
T is the truck chassis cycle emission value.
N is the number of comparable cycle sets.

1. "Emissions and Fuel Economy Test Results for Methanol and Diesel-Fueled Buses," Gilles A. Eberhard, Matthew Ansari, and S. Kent Hoekman; Chevron Research Company; Air & Waste Management Association 82nd Annual Meeting & Exhibition June 25-30, 1989.