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Heavy Duty Diesel Particulate Emission Factors

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1. Background

One of the operating characteristics of diesel engines is their emission of particulate matter, part of which can be seen as visible smoke while the remainder is invisible. At temperatures above about 260°C (500°F), it is believed(1) that the particulate is principally made up of small agglomerated chains (about 1 micron long) of very small spheres of elemental carbon (soot). At temperatures below about 260°C, these chains are frequently coated with condensed material mostly in the form of high molecular weight organic compounds, unburned hydrocarbons, some sulfur dioxide, sulfates, and polynuclear aromatic hydrocarbons (PNA).

EPA has studied particulate emissions from diesel engines for the last several years. The first such interest was in studying the visible smoke component of particulate which was followed by PNA studies of diesel exhaust. At about the same time as sulfate particulate emissions from gasoline vehicles were beginning to be studied (1973), EPA started measuring total particulate from heavy duty diesel engines. Since this time, interest in diesel particulate emissions has greatly increased, which has in part been due to preliminary results indicating the potentially carcinogenic nature of portions of the soluble organics from diesel particulate. Also, the Clean Air Act As Amended August 1977 includes a requirement for a motor vehicle particulate standard effective with the 1981 model year(2)*, thereby greatly increasing interest in particulate emissions characterization.

2. Experimental Procedures

The fundamental objective in particulate sampling to date has been to obtain a sample that is as close as possible to actual atmospheric particulate. As such, the exhaust and attendant particulate is quenched to temperatures of 52°C (125°F) or less at the sampling point. This is consistent with the currently accepted definition of mobile source particulate being anything that is collected on a specified filtering medium that is maintained at or below 52°C, excluding condensed water. The sampling temperature of 52°C has been selected as an appropriate sampling point temperature for research purposes.

The methods that have been used to meet the sampling objectives for heavy duty diesel engines have, in part, been adapted from technology that was developed for light duty gasoline vehicle particulate sampling. This involves the use of a dilution tunnel wherein engine exhaust is mixed with dilution air and a sample of the mixture is filtered for particulate emission rate determination. The major adaptation for heavy duty diesels has been the use of an exhaust flow splitter which is necessary because the large volumes of exhaust flow (in some engines, in excess of 0.47 m^3/s or 1000 cfm) would require extremely large tunnel

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* Numbers in parenthesis represent References found in back of paper.

flow capacity (7.0 m^3/s or 15,000 cfm) to dilute the exhaust to 52°C. Such large tunnel flows would require extremely large blowers (with a very high initial capital equipment cost) and it would be difficult to measure such large flows accurately. Therefore, the research work in heavy duty diesel particulate has, to date, been done with an exhaust splitter thus permitting lower, somewhat more easily measured tunnel flows as well as permitting the use of available CVS equipment.

In the exhaust splitter system, the engine-out exhaust is introduced into a commercially-available muffler (of a type normally used with the engine being tested), which contains two perforated tubes. One of these tubes exits the muffler and leads to waste, and the other tube goes to the dilution tunnel. The tubes are identical in perforations and length but are different in outlet diameter. The objective in building the splitter is to give exhaust components an equal probability of exiting by the dilution tunnel line or the waste line. In the research performed to date, each engine is tested with a specifically tailored splitter so that the resultant flow to the dilution tunnel is sufficient to obtain an adequate sample yet not so much as to result in excess temperatures at the filter face. Some control is exerted over flow from the splitter to the dilution tunnel by restricting the flow to waste.(3)

There are various types of filter media upon which diesel particulate samples have been collected. With any filter, including glass fiber, there exists the possibility of artifact formation from chemical reactions occurring on the filter during collection. This could be a problem if the collected material were to be analyzed chemically, but when particulate mass is the principal measurement to be made, the normal procedure has been to use 47 mm glass fiber filters due to their good particulate collection efficiency and their relatively low tendency toward filter plugging.

In the EPA work at Southwest Research Institute, particulate mass emission rates have also been computed from the 47 mm PTFE (polytetrafluoroethylene, known as Teflon and made into filters with a trade name of Fluoropore) filters. PTFE filters are used when sulfate emissions are to be measured, because unlike glass fiber filters, the PTFE filters have a low, relatively constant background sulfate level. However, they clog easily and therefore are not usually the filter of choice for particulate mass emissions sampling. A third source of particulate emission data for diesels comes from 20.3 cm by 25.4 cm (8 x 10 in.) glass fiber filters through which higher flow rates are pulled so that sufficient sample is obtained for PNA and other organic compound analyses. However, results indicate that the particulate emissions results are partially a function of the filtering medium and filtering system employed.(3) This is due to factors such as different filter retention characteristics and different wall effects of various systems. Therefore, it is important to specify what type of filter medium and system have been used to obtain particulate emission results. All data reported in this paper were derived from samples collected on 47 mm glass fiber filters.

A study was recently performed for EPA(4) wherein 54 filter media were evaluated as to the appropriateness of their use for collecting particulate matter in automobile exhaust. The parameters measured in the study included aerosol collection efficiency, flow resistance, face velocity, filter density, water and organic vapor sorption, manufacturing uniformity, fiber blow-off, filter loading and exposure to exhaust gases. The results of this study indicated that one of the optimum filter media was the Teflon-on-fiber glass filter (Pallflex Products Corporation is one manufacturer of filter media of this type). It is likely that EPA will be using filter media of this type in the future.

During the course of EPA's heavy duty diesel particulate characterization work, the resultant particulate emissions data has been reported in several units, including fuel specific (grams particulate per kilogram of fuel, g/kg fuel) and work specific (grams particulate per kilowatt hour, g/kw hr). It seems that each unit has both strong advantages as well as certain disadvantages. The work specific units seem particularly well suited for use in regulating particulate emissions. This was also the conclusion reached when units were being considered for gaseous emissions regulation.(5)

The work specific units have two disadvantages. The first is that, in the steady state modal weighting procedure, the composite weighted emission number has a slight high bias in that the significant idle particulate emissions are not offset by a finite power output. The other disadvantage is that it is very difficult to compute a meaningful overall emission factor* from a work specific number.

These disadvantages are overcome by using fuel specific units. The fuel specific units take into full account the idle mode emissions as there is fuel flow at idle. Also, these units are much more meaningful in computing particulate emission factors as there is quite a bit of fuel usage data available, both on a gross scale and individual vehicle scale. The two units are very closely related by the work specific fuel consumption which is relatively constant over a wide range of engines. The major disadvantage of using these units from a regulations point of view is that they would tend to give a certain amount of advantage to less efficient engines. At this time it has not been decided which units EPA will use for regulation of heavy duty particulate. It is possible that EPA may regulate particulate emissions on the basis of work specific units but may require reporting in both these units as well as fuel specific units.

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* The term "emission factor" is used to indicate an emission rate in terms of mass per distance traveled.

The particulate data that has been gathered to date has been based on the 13 steady state operating modes of the Federal Test Procedure(6). The method for computation of composite emissions from this type of modal data was stated by Bascom et al..(5), but the derivation of that method was not. The derivation which follows(7) was used for reducing the modal data which is reported in this paper.

Notation:

i = mode number
W_i = time-based weighting factor
= $(\text{time})_i / \Sigma(\text{time})_i$
F_i = mode fuel rate, kg/hr
P_i = mode power, kW
Pt_i = mode particulate rate, g/hr

DERIVATION 1 - Grams per hour units

Cycle pollutant emissions (g/hr) = P_{gh}, where

$$P_{gh} = \text{grams pollutant emitted during cycle} / \text{cycle time, hours, or}$$

$$P_{gh} = \Sigma_i \left(\begin{matrix}\text{grams pollutant}\\ \text{produced in mode}\end{matrix}\right)_i \Big/ \Sigma_i (\text{time})_i .$$

Using the above notation,

$$P_{gh} = \Sigma_i Pt_i \ (\text{time})_i / \Sigma_i \ (\text{time})_i ,$$

and substituting gives

$$P_{gh} = \Sigma_i Pt_i W_i .$$

DERIVATION 2 - Work specific units

Cycle pollutant emissions (g/kW hr) = P_{gkh}, where

$$P_{gkh} = \text{grams pollutant emitted during cycle} / \text{work performed during cycle, or}$$

using the above notation

$$P_{gkh} = \Sigma_i \ Pt_i (\text{time})_i / \Sigma_i P_i (\text{time})_i .$$

Dividing the numerator and denominator by total cycle time yields,

$$P_{gkh} = \frac{\Sigma_i \ Pt_i (\text{time})_i / \Sigma_i (\text{time})_i}{\Sigma_i P_i (\text{time})_i / \Sigma_i (\text{time})_i}$$

which, upon subsitution, reduces to

$$P_{gkh} = \Sigma_i \ Pt_i W_i / \Sigma_i P_i W_i .$$

DERIVATION 3 - Fuel specific units

Cycle pollutant emissions (g/kg fuel) = P_{gkf}, where

P_{gkf} = grams pollutant emitted during cycle / kg fuel consumed over cycle, or

using the above notation

$$P_{gkf} = \Sigma_i Pt_i (time)_i / \Sigma_i F_i (time)_i .$$

Dividing the numerator and denominator by total cycle time yields,

$$P_{gkf} = \frac{\Sigma Pt_i (time)_i / \Sigma_i (time)_i}{\Sigma F_i (time)_i / \Sigma_i (time)_i}$$

which, upon substitution, reduces to

$$P_{gkf} = \Sigma_i Pt_i W_i / \Sigma_i F_i / W_i .$$

3. Results

The currently available data that EPA has developed regarding the particulate emission rates from heavy duty diesel engines is presented in Tables I and II. These data come from four EPA contractual projects at Southwest Research Institute, three of which are completed (8)(9)(10), and one is underway(11). An "Engine Number" is assigned to each test engine for easy reference.

Engine numbers 1 (DDAD 6L-71T, two-stroke) and 5 (Cummins 855 TC, four-stroke) were run in a program(9) that was designed to develop a methodology for determining fuel effects on heavy duty diesel particulate emissions. As such, three diesel fuels were run in the two engines. The three fuels were a DF#1, a DF#2, and a DF# "1 1/2" which was designed to have characteristics between those of DF#1 and DF#2. Each of these fuels then was doped with a fuel additive and the engines run again. The DF#1 was run with Ethyl DII-2 at the field usage level of 0.10% by volume. The DF#2 and DF#1 1/2 were doped with Lubrizol 8005 at the field usage level of 0.25% by volume.

The Ethyl DII-2 is a primary hexyl nitrate (organic) material intended for use as an ignition accelerator or "cetane improver". Lubrizol 8005 is an organo-metallic used as a smoke suppressant, containing calcium and a small amount of barium.

Engines number 2 (DDAD 6V-71, two-stroke) and 6 (Caterpillar 3208, four-stroke) were run in a program(10) wherein several types of fuels have been run to note the effect of the fuel on the emissions from the two engines. The fuels used were 1) No. 2 Diesel fuel (DF#2) emission test fuel, 2) DF#2 which closely approximates a "national average" fuel, 3) DF#1, 4) DF#2, "minimum" quality, which has a low cetane (about 42) and is high in aromatics, and 5) DF#2, "premium" quality, which has a high cetane (about 52) and is high in paraffins.

Engines 3 and 7 were run in a program(8) that characterized the emissions from these engines under two different configurations each. The Detroit Diesel Allison Division (DDAD) 6V-71 engine was operated with both Low Sac Needle size 60 (LSN-6) fuel injectors and B-60E injectors. The B-60E injectors are needle type with a constant end of injection helix instead of a constant start of injection helix. The Cummins 855 TC four-stroke engine was operated in a "current" configuration where the engine used standard static injection timing and in a "low" emissions configuration where variable injection timing was employed. Engine number 4 (DDAD 8V-71TA, two-stroke) was run in the same program but in just one configuration which represented the production engine. Engines number 3 and 4 were operated on commercially available DF#1 and engine number 7 was run on a DF#2 with nominally "national average" characteristics.

Table I

Table of Fuel Specific Particulate Emission Rates for Two-Stroke Heavy Duty Diesel Engines

Engine Number	Engine	Test Fuel	Test Conditions	Particulate Emissions g/kg Fuel: Test Result	σ's from Mean
1	6L-71T	DF1	Normal	3.8	0.71
1	6L-71T	DF1	Ignition accelerator additive used in fuel	3.7	0.78
1	6L-71T	DF2	Normal	3.7	0.78
1	6L-71T	DF2	Smoke suppressant used in fuel	4.6*	0.11
1	6L-71T	DF"1.5"**	Normal	3.4	1.00
1	6L-71T	DF"1.5"**	Smoke suppressant used in fuel	3.7	0.78
2	6V-71	DF2 Emissions	Normal	6.18	1.07
2	6V-71	DF2 Nat. Avg.	Normal	6.61	1.39
2	6V-71	DF1	Normal	5.69	0.71
2	6V-71	DF2 Min. Qual	Normal	5.89	0.86
2	6V-71	DF2 Premium	Normal	6.52	1.33
3	6V-71	DF1	LSN 60 Injectors	4.43	0.23
3	6V-71	DF1	B 60E Injectors	5.75	0.75
4	8V-71TA	DF2	Normal	2.45	1.71
			Average	4.74	
			Standard Deviation (σ)	1.34	

* Data corrected for injector malfunction error via personal communication with authors.

** A DF with properties between DF#2 and DF#1

Table II

Table of Fuel Specific Particulate Emission Rates for Four-Stroke Heavy Duty Diesel Engines

Engine Number	Engine	Test Fuel	Test Conditions	Particulate Emissions g/kg Fuel: Test Result	Particulate Emissions g/kg Fuel: σ's from Mean@
5	855 TC	DF1	Normal	1.0	0.73
5	855 TC	DF1	Injection accelerator additive used in fuel	0.95	0.75
5	855 TC	DF2	Normal	1.6	0.47
5	855 TC	DF2	Smoke suppressant used in fuel	2.0	0.29
5	855 TC	DF"1.5"**	Normal	1.2	0.64
5	855 TC	DF"1.5"**	Smoke suppressant used in fuel	1.3	0.60
6	3208	DF2 Emissions	Normal	3.11	0.20
6	3208	DF2 Nat. Avg.	Normal	3.09	0.19
6	3208	DF1	Normal	1.82	0.36
6	3208	DF2 Min. Qual.	Normal	3.36	0.31
6	3208	DF2 Premium	Normal	2.94	0.12
7	855 TC	DF2	"Fixed" Timing	1.44	0.54
7	855 TC	DF2	"Variable" Timing	2.09	0.25
8	ETAY(B) 673A	DF2	Normal	3.53	0.52
9	3208 (EGR)	DF2	Normal	10.16	3.30
			All engines		
			Average	2.64	
			Standard Deviation (σ)	2.27	
			All engines, except #9		
			Average	2.10	
			Standard deviation(σ)	0.96	

@ The "all engines" mean and standard deviation

** A DF with properties between DF#2 and DF#1

Engines 8 (Mack ETAY(B) 673A, four-stroke) and 9 (Caterpiller 3208 EGR,* four-stroke) were tested in a program(11) that is currently in progress. Both engines were tested in production configurations with DF#2. Engine number 9 is noteworthy as it is the only test engine to have EGR.

The data are presented in two groups, the four-stroke and two-stroke engines. This is because the data developed to date indicate that the two-stroke engines tend to emit almost twice the particulate as the four-stroke engines (with the exception of the 4-stroke EGR engine, which emitted almost 4 times the particulate as the average non-EGR 4-stroke engine). Since the objective is to establish a particulate emission rate that is representative of actual conditions, all data in each of these two groups are averaged together with no special statistical consideration given to the individual results. This is felt to be justified as most test fuels and conditions can be expected to be encountered in actual use. Those tests run under somewhat non-actual use conditions

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* Exhaust Gas Recirculation

(e.g. DF1 or 1.5 in a 4-stroke) yielded results that varied from the mean by one standard deviation or less. Therefore, in general the averaged results are considered to be representative of actual use.

All of the data presented represent particulate emission rates computed from 47 mm glass fiber filter analysis results. Also, all of the data is relatable to 13 mode data. However, all of the data may not have been computed from tests in which 13 discrete filters were taken. Some data come from 7 mode tests which used distributed weighting factors similar to 13 mode weighting factors to arrive at a composite particulate emission rate.

In order to compute a meaningful heavy duty diesel particulate emission factor, several types of data are required. These include 1) fuel specific particulate emission rates for heavy duty diesel vehicles, 2) heavy duty diesel average speed data, and 3) heavy duty diesel fuel usage data. All of this data should be representative of actual use conditions. Much, but not all, of this data is currently available.

The first type of data required is the in-use fuel specific particulate emission rate. The available data has been presented in Tables I and II. However, this data is representative only of a few select number of engines operated at steady state modes under laboratory conditions. Therefore, the data is not necessarily representative of actual in-use particulate emission rates.

EPA is currently initiating a program to study particulate emission rates of heavy duty diesel engines operated over transient cycles. This should significantly improve the estimates of in-use particulate emissions. It is expected that transient operation will yield higher particulate emission rates.

For the purposes of this analysis, the data presented in Tables I and II will be used with only one minor change. The four-stroke emission factor that will be used will be the one excluding the EGR engine (2.10 g/kg fuel). This is because the EGR engine represents only about 1.4% of current engines sold(12) and a much lower percent of the total heavy duty diesel engine population. By eliminating the result from that engine, the particulate emission factor becomes more representative of results from steady state, laboratory tests of the general heavy duty diesel population.

The second type of data required for a meaningful heavy duty diesel engine factor is average speeds for actual heavy duty diesel vehicle usage. Data of this type was developed by the Coordinating Research Council CAPE-21 project wherein trucks and buses were instrumented and operated in typical use in Los Angeles and New York City. Four buses were used for data accumulation in each city as well as 17 diesel trucks in Los Angeles and 14 diesel trucks in New York City. The data thus obtained was reduced by an EPA contractor(13) and is presented in Table III. These average speed data will be used for selecting the fuel economy values used in computing the particulate emission factors. The data from the two cities can be considered to represent extremes of urban heavy duty vehicle usage, with usage in other cities falling somewhere in between these values.

Table III

Average Vehicle Speeds for Heavy Duty Diesel Vehicles Under Various Types of Usage

City	Usage Type	Average Speed (km/hr)	
		Diesel Trucks	City Buses
Los Angeles	Non-Freeway	25.6	26.8
	Freeway	74.9	73.3
	Combined	49.6	31.9
New York	Non-Freeway	14.4	12.5
	Freeway	43.6	34.5
	Combined	20.7	12.7

The third type of data required is fuel usage data for heavy duty diesel vehicles. Such data comes from a study(14) wherein emissions and fuel consumption data were gathered from a wide variety of heavy duty vehicles under several types of duty cycles tested on chassis dynamometers. Among the vehicles tested were twelve diesel trucks (eight equipped with 4-stroke engines and four with 2-stroke engines) and two city buses, both with 2-stroke engines (the typical bus engines). The duty cycles over which the trucks were tested included eight steady state speeds (0, 5, 10, 15, 20, 30, 40 and 55 mph), four driving cycles (average speeds of 5, 10, 15 and 20 mph) and three sinusoidal driving schedules (20 ± 5, 30 ± 5 and 40 ± 2 mph). The buses were operated over duty cycles that included seven steady states (0, 5, 10, 15, 20, 30 and 40 mph), four driving cycles (5, 10, 15 and 20 mph average speed) and two sinusoidal driving schedules (20 ± 5 and 30 ± 5 mph). The data was obtained under laboratory conditions and does not represent on-road fuel consumption which could be higher. All of the vehicles were tested with dynamometer inertia weights corresponding to the vehicle fully loaded, half loaded and empty.

The fuel consumptions developed in this study are for a series of quite uniformly spaced speed points whereas the vehicle usage average speeds (Table III) are at intermediate points. Therefore, simple linear interpolation was used to determine the fuel consumption values for trucks (and engines) and buses for the vehicle usage average speeds. The results of these calculations are presented in Table IV.

With the fuel consumption values thus determined, the particulate emission factors can be computed from the following formula:

Part. Emission Factor (g/km) = (particulate emissions)(fuel conversion)(fuel consumption)

= (g part./kg fuel)(0.851 kg fuel/litre fuel)(litre fuel/100 km)(1/100)

The results of these calculations are presented in Table V. This table should be consulted for specific emission factor numbers as an overall heavy duty diesel particulate emission factor number is less meaningful. However, if a condensation must be made, it can be partially done on the basis of vehicle sales(12). About 1.78 percent of the heavy duty vehicles sold in 1975 were buses. Of the remaining 98.22% (trucks), 23.44% were 2-stroke (all of the Detroit Diesel engines, the only manufacturer of 2-stroke) for a weighting factor of 23.02%. The 4-stroke engines represent 76.56% of the trucks for a weighting factor of 75.20%. Using these weighting factors on the half load, combined usage emission factors yields a weighted New York City usage emission factor of 1.31 g/km and a Los Angeles usage emission factor of 0.83 g/km. Therefore, the heavy duty vehicle particulate emission factor for half loaded vehicles operating in urban areas (combination of both freeway and non-freeway use) is between 0.84 and 1.31 g/km, depending on the average speed of use. This figure assumes no engine malfunction, is based on steady state, laboratory emission results and uses laboratory fuel consumption values.

It must be emphasized that the most accurate emission factor for heavy duty vehicles is obtained by using Table V. This is especially important when the vehicle mix deviates from the mix used to compute the weighting factors. For example, it is conceivable that, in a downtown area where trucks are prohibited from the streets and the only heavy duty diesel vehicles are buses, the emission factor would be between 1.84 and 2.66 g/km (half loaded buses, combined usage) which is significantly higher than the above-mentioned composite emission factor.

Table IV

Table of Fuel Consumption Values
Used in Computing Particulate Emission Factors

Vehicles, Engines, Loads	Average Fuel Consumption (ℓ/100 km)**					
	New York City			Los Angeles		
	Non-Freeway	Freeway	Combined	Non-Freeway	Freeway	Combined
Trucks	(14.4)*	(43.6)	(20.7)	(25.6)	(74.9)	(49.6)
2-Stroke						
Empty Load	55.2	32.3	48.4	45.0	35.9	30.7
Half Load	60.3	38.4	55.2	52.4	42.1	36.1
Full Load	70.0	46.4	65.7	63.4	48.5	42.5
4-Stroke						
Empty Load	52.8	33.0	46.0	42.9	32.4	30.7
Half Load	60.9	37.6	54.8	51.7	37.5	34.9
Full Load	69.0	44.3	63.9	60.8	43.0	40.8
Buses	(12.5)	(34.5)	(12.7)	(26.8)	(73.3)	(31.9)
Empty Load	64.3	43.9	63.9	48.4	35.6	45.3
Half Load	66.5	44.6	65.9	47.6	41.6	45.5
Full Load	73.5	49.6	73.1	53.5	47.7	50.8

* Numbers in parentheses represent average speed (km/hr) at the three usage conditions for the two cities. These numbers come from Table III.

** Based on data collected under laboratory conditions, on-road fuel consumption may be higher.

Table V

Table of Heavy Duty Diesel
Vehicle Particulate Emission Factors

Vehicles, Engines, Loads	Particulate Emission Factors (g/km) **					
	New York City Usage			Los Angeles Usage		
	Non-Freeway	Freeway	Combined	Non-Freeway	Freeway	Combined
Trucks	(14.4)*	(43.6)	(20.7)	(25.6)	(74.9)	(49.6)
2-Stroke						
Empty Load	2.2	1.3	2.0	1.8	1.5	1.2
Half Load	2.4	1.6	2.2	2.1	1.7	1.5
Full Load	2.8	1.9	2.7	2.6	2.0	1.7
4-Stroke						
Empty Load	1.0	0.6	0.8	0.8	0.6	0.6
Half Load	1.1	0.7	1.0	0.9	0.7	0.6
Full Load	1.2	0.8	1.2	1.1	0.8	0.7
Buses	(12.5)	(34.5)	(12.7)	(26.8)	(73.3)	(31.9)
Empty Load	2.6	1.8	2.6	2.0	1.4	1.8
Half Load	2.7	1.8	2.7	1.9	1.7	1.8
Full Load	3.0	2.0	3.0	2.2	1.9	2.1

* Numbers in parentheses represent average speed (km/hr) at the three usage conditions for the cities These numbers come from Table III.

** Based on data collected under laboratory conditions, on-road emission factors may differ.

There have been other studies of Diesel particulate emissions, but results of such studies can't be compared directly with the emission factors in Table V because those studies address particulate emissions only in terms of mass per volume exhaust, mass per time, mass per fuel used, or mass per work output, rather than mass per distance traveled. However, a comparison of the fuel specific emission rates in Tables I and II with corresponding results from some other studies (3, 15, 16) indicates that the range of engines and operating conditions used in this study is wide enough to be representative of other studies.

The emission of particulate from heavy duty diesel vehicles yields some interesting figures from a national emission inventory point of view. Such an inventory has been computed from fuel consumption figures(18) shown in Table VI. The truck emissions were computed assuming that 23% of the trucks are 2-stroke and the remainder 4-stroke. All of the buses are assumed to be 2-stroke. One of the more important sources of urban particulate emissions are the local buses, which, according to the computations, emit 5570 metric tons of particulate per year in urban areas. To this urban particulate emission rate must be added the component attributable to trucks and, to a lesser degree, intercity buses.

Table VI
Table of Diesel Fuel Consumption and Particulate Emissions
for Three Types of Highway Heavy Duty Diesel Vehicles

Emission Source	1975 Fuel Consumption (million barrels)	Particulate Emissions (metric tons/year)
Trucks, diesel	216.28	79,850
Intercity buses	4.29	2,750
Local buses, diesel	8.69	5,570
TOTAL	229.26	88,170

4. Conclusions

A. Based on tests done for EPA by Southwest Research Institute, the average particulate results from steady state laboratory tests for 2-stroke engines is 4.74 g/kg fuel and for 4-stroke engines is 2.64 g/kg fuel.

B. The emission factor range for urban areas which permit only local buses is from 1.8 to 2.7 g/km (2.9 to 4.3 g/mi) of particulate. This assumes all half load buses, combined usage (which is very close to non-freeway usage), no engine malfunctions and on-road fuel consumption equal to the laboratory fuel consumption, and is based on steady state particulate test results.

C. Diesel trucks emit, on a nationwide scale, 80,000 metric tons of particulate per year, intercity buses emit 2,800 metric tons particulate/year and local buses emit 5,000 metric tons per year for a total of 88,000 metric tons of particulate per year.

EPA is initiating a study of particulate emissions (and fuel economy) under laboratory transient operating conditions. The transient cycle will represent urban heavy duty vehicle use and will therefore yield results that more accurately reflect such use.

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