United States
Environmental Protection
Agency

Air and Radiation

EPA420-R-02-025
October 2002

Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices

EPA420-R-02-025
October 2002

Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices

Han Lim

Certification and Compliance Division
Office of Transportation and Air Quality
U.S. Environmental Protection Agency

NOTICE

This technical report does not necessarily represent final EPA decisions or positions. It is intended to present technical analysis of issues using data that 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.

ABSTRACT

Heavy duty diesel truck idling contributes significantly to energy consumption in the United States. President Bush's May 2001 *National Energy Policy* tasks the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Transportation (DOT) to reduce truck idling. Consequently, the EPA initiated a study that would quantify long duration idling emissions and fuel consumption rates.

The idling study was conducted over a two year period at the U.S. Army's Aberdeen Test Center (ATC). A short introductory study with five tests was done in June 2001 and a larger study with 37 tests in May 2002. In the larger study, EPA worked with Oak Ridge National Laboratory (ORNL) and Rowan University with funding from the New Jersey Department of Transportation (NJDOT).

In total, ATC performed 42 tests on nine class-8 trucks (model years ranging from 1980's to 2001). Two of those trucks were equipped with 11 hp diesel auxiliary power units (APU's), and one was equipped with a diesel direct fired heater (DFH). The APU powers electrical accessories, heating, and air conditioning, whereas a DFH heats the cab in lieu of truck idling. All tests were run in a climate controlled chamber, where the trucks idled at high and low RPMs in the following environments: 90^{O}F with air conditioning on, 0^{O}F with the heater on, and 65^{O}F with no accessories on. ATC test technicians adjusted the air conditioning or heater to maintain a target cab temperature of 70^{O}F. Each idling test was run for approximately three hours.

EPA's ROVER (Realtime On-road Vehicle Emissions Reporter) and ORNL laboratory emissions instruments were simultaneously used for measuring fuel consumption rates, HC (hydrocarbons), NOx (nitrogen oxides), CO (carbon monoxide), CO_2 (carbon dioxide), O_2 (oxygen), and PM (particulate matter) (ORNL only) during the May 2002 test runs. Only the ROVER was used during June 2001. The test data showed that, based on the data obtained from this study: (a) on average, a typical 1980s-2001 model year idling truck emits 144 g/hr of NOx and 8224 g/hr CO_2 and consumes about 0.82 gal/hr of diesel fuel; (b) there is good test repeatability when measuring idling emissions; and (c) use of an APU can reduce idling fuel consumption by 50% to 80% and reduce NOx by 89% to 94% whereas use of a DFH can reduce fuel consumption by 94% to 96% and reduce NOx by 99%.

INTRODUCTION

In May 2001, President Bush issued the *National Energy Policy* directing EPA and DOT to work with the trucking industry to establish a program to reduce emissions and fuel consumption from long-haul trucks. Responding to this directive, EPA initiated a comprehensive program aimed at reducing idling. This includes organizing workshops, issuing grants, implementing demonstration projects, and most importantly, closely examining idling fuel consumption and exhaust emissions.

EPA ran a two-phase test program. Phase 1 consisted of a small sample of trucks and one APU, which was completed in June 2001. The results of this phase prompted EPA to develop a more comprehensive test program (Phase 2), completed in May 2002.

Certain stakeholders reviewed and commented on the May 2002 test protocol and actual field tests, including the American Trucking Association (ATA), Rowan University, and the 21st Century Truck Partnership (a government-industry partnership). The phase 2 test program was funded by the New Jersey Department of Transportation (NJDOT) using the DOT Congestion Mitigation and Air Quality (CMAQ) funds. The final test protocol that was used for the May 2002 testing incorporated comments from the above mentioned organizations, as well as ATC and ORNL.

Long haul truck drivers idle their engines during their rest periods to provide heat or air conditioning for the sleeper compartment, keep the engine warm during cold weather, and to maintain adequate battery voltage while using electrical appliances such as a microwave oven or television set. Other reasons cited by truck drivers for idling include safety (i.e., keeping the windows closed, thereby needing cooling or heating) and habit (i.e., protecting the engine by not turning it off).

The precise number of long-duration idling trucks is not known. Estimating the potential number of idling trucks requires examining several sources. The U.S. Census

Bureau, Vehicle Inventory and Use Survey (VIUS) (1997), estimates that approximately 500,000 heavy duty trucks (> 26,001 lbs) travel more than 500 miles as their average daily trip length. Driving this distance may require an eight hour rest period, and during this rest period truck drivers may idle their engines.

The uncertainty on idling trucks extends to the hours and number of days over a year spent idling. Some reports indicate 6-8 hours per day over 250-300 days per year. Since DOT mandates a rest period of 8 hours after a maximum of 10 hours of driving, it is possible to conclude idling times of 1,500-2,400 hours per year.

While exact numbers, hours, and days are currently unavailable, the objective of the test program was to better understand the fuel consumption and exhaust emissions associated with idling trucks under different weather and accessory loads.

METHODOLOGY

To measure actual emissions from a truck's tailpipe, EPA used the EPA-developed ROVER (Realtime, On-highway Vehicle Emissions Reporter) system. ROVER allows mass emissions data to be obtained simultaneously with vehicle/engine parameter data from the truck's diagnostic port along with vehicle location and speed data using an integrated global positioning system (GPS). Other instruments can also be used by communicating through auxiliary analog channels or serial ports.

Initially, ATC was directed to perform a 6 hour idling test to determine the point when the pollutants reach steady state conditions. Initial tests showed steady state emissions at 3 hours. Therefore, every subsequent test was run for 3 hours. Once the data were collected, EPA staff analyzed the data and evaluated the baseline idling emissions for these nine trucks, two APU's, and one DFH.

Truck Selection

Trucks of various ages that represent highway trucks from the 1980's to present day were obtained for testing. ATC used class-8 trucks that were available at the Aberdeen Test Proving Grounds and commercially available truck rentals such as Ryder that ranged from mid-1980's to 2001. Various model year trucks were selected including three representing the model years near the pivotal highway diesel engine standards change years 1997 (5.0 g/bhp•hr NOx standard) to 1998 (4.0 g/bhp•hr NOx standard). Table 1 below shows the descriptions of each truck. The grey blocks in Table 1 represent trucks and APU tested in June 2001, the white blocks represent trucks, APU, and DFH tested in May 2002.

Table 1: Truck and Engine Identification

Truck and Engine	Rated HP and engine displacement	Additional Truck Information as available
1985 Volvo White** 1990 Volvo NTC-400	400 @ 2100 rpm 855 CID (14.0 L)	Engine # 11611170, date of mfr. 12/90
1992 Ford* 1992 Caterpillar 3406B	425 @ 2000 rpm 890 CID (14.6 L)	Engine Family NCT0893FPB9 Serial No. 3ZJ23694
1995 International (Navistar) 1995 Detroit Diesel S60	470 @ 2100 rpm 774 CID (12.7 L)	Engine Family: SDD12.EJDARA approx. age: 650,000miles
1997 International (Navistar) 1997 Caterpillar 3406	410 @ 1800 rpm 890 CID (14.6 L)	Engine Family: VCP893EZDARX Serial No. 6TS09138
1998 Freightliner 1997 Cummins	370/435 @ 1800 rpm	Engine Family: VCE855FJDARA Serial No. 11861993
1999 Volvo 1999 Detroit Diesel S60	470 @ 2100 rpm 774 CID (12.7 L)	Engine Family: XDDXH12.7EGL Serial No. 06R0-547668
1999 KenworthT800 1998 Caterpillar 3406	410 @ 1800 rpm 890 CID (14.6 L)	Engine Family: WCPXH0893ERK
2000 Volvo 2000 Detroit Diesel Series 60	470 @ 2100 rpm 774 CID (12.7 L)	Engine Family YDDXH12.7EGL 4V4NC9RH31N247483
2001 Freightliner 2000 Detroit Diesel Series 60	500 @ 2100 rpm 774 CID (12.7 L)	Engine Family YDDXH12.7EGL Serial No. 06R0612467
Idle Reducing Devices:		
1995 Pony Pack APU: Kubota Z200		
2000 Pony Pack APU: Kubota Z482	11 @ 3600 rpm 29.23 CID (0.482 L)	Engine Family YKBXL.719KCB Serial # YC4323
1990's Espar Diesel Direct Fired Heater Model D1LC		

NOTES: Grey blocks represent June 2001; elsewhere May 2002 *
Only truck without a sleeper cab nor ECM data port **
No ECM (engine control module diagnostic port) available
The horsepower ratings are obtained from the engine label (advertised hp)

Each truck was equipped with a sleeper cab (except as noted in Table 1) air conditioning and heating.

Trucks were not subjected to any special maintenance procedures (e.g., oil changes, tune-ups, etc.). All trucks were tested as received or as rented, including the standard diesel fuel (standard filling station fuel) that all trucks were equipped with.

Test Conditions / Scenarios / Variables

All tests were run in a climate controlled chamber, approximately 40 ft x 40 ft x 24 ft, where the trucks were idled at high and low RPMs in the following environments: 90°F with air conditioning operating, 0°F with the heater operating, and 65°F with no accessories operating. Table 2 shows all the test scenarios for phase 1 (June 2001) and phase 2 (May 2002).

Table 2: Test Matrix

JUNE 2001 TEST SCENARIOS			
	A/C On Chamber Temp=90°F	Heater On Chamber Temp=0°F	No Accessory Chamber Temp=65°F
1985 Volvo White - 1 test	750 RPM	N/A	N/A
1995 International - 1 test	600 RPM	N/A	N/A
1999 Kenworth - 1 test	600 RPM	N/A	N/A
2000 Volvo - 1 test	1000 RPM	N/A	N/A
1995 APU - 1 test	3600 RPM	N/A	N/A
MAY 2002 TEST SCENARIOS			
1992 Ford - 6 tests	600 RPM	600 RPM	600 RPM
	1200 RPM	1200 RPM	1200 RPM
1997 International 6 tests	700 RPM	700 RPM	700 RPM
	1100 RPM	1100 RPM	1100 RPM
1998 Freightliner - 8 tests*	600 RPM	600 RPM	600 RPM
	800 RPM*	N/A	N/A
	1000 RPM*	N/A	N/A
	1200 RPM	1200 RPM	1200 RPM
1999 Volvo - 6 tests plus 2 repeats**	600 RPM	600 RPM	600 RPM x3**
	1200 RPM	1200 RPM	1200 RPM
2001 Freightliner - 6 tests	600 RPM	600 RPM	600 RPM
	1200 RPM	1200 RPM	1200 RPM
2000 APU - 2 tests	3600 RPM	3600 RPM	N/A
1997 DFH - 1 test	N/A	High Heat	N/A

NOTES: Total number of tests = 42
A/C = air conditioning; none = no accessories active
* Performed additional tests at the intermediate speed to examine emissions/ fuel consumption rates with varying engine RPM.
** Performed two repeat tests at 600 RPM with no accessories active to assure good test to test repeatability

The APU tests were run with the air conditioning operating and heater on in the 90°F and 0°F environments, respectively. However, the DFH test was run only in the 0°F environment. ATC test technicians adjusted the air conditioning or heater to maintain a target cab temperature of 70°F. EPA staff developed a test matrix to examine the following primary test variables: engine RPM, truck age, and accessory load.

The engine RPM was usually dialed in via electronic onboard controls in the truck cab, except for the 1985 Volvo White truck which did not have the electronic control feature. The 1985 Volvo truck was only tested at one rpm. Most trucks were capable of idling from 600 to 1200 rpm. The RPM was set at one value throughout a three hour test.

Test Equipment

ATC staff used the EPA-developed ROVER system which is comprised of an IBM PC based data acquisition system running EPA developed software, a Snap-On™ gas analyzer, an optional Horiba MEXA-120 zirconia NOx sensor, and specially designed exhaust gas flowmeter modules of various sizes.

ROVER is used to measure fuel consumption rate, HC, CO, CO_2, and NOx emissions. In the Snap-On MT3505 analyzer, non-dispersive infrared technology is used to measure HC, CO, and CO_2, whereas an electrochemical sensor is used to measure NOx and O_2. Generally, the electrochemical and zirconia based NOx measurements showed good comparability, however during the second phase of this testing program, there was a zero-drift error in the electrochemical sensor which could not be readily rectified. Hence, only the Horiba NOx results are presented. Furthermore, a zirconia NOx instrument such as the Horiba MEXA-120 was appropriate for the experiments in this study. SAE Paper 2001-01-3619 contains information that shows a zirconia NOx instrument has a 4 to 1500 ppm linear calibration at ± 5% measured point accuracy versus primary standards (Schenk et al, 2001). The appropriate gas flowmeter module was attached to the exhaust pipe of the specimen truck.

Since the Pony Pack™ engine was equipped with a smaller diameter exhaust pipe than the main engine, a smaller flowmeter was used. The appropriate flowmeter module also provided the gas sample to the gas analyzer and temperature and pressure measurements needed for mass determinations. Fuel consumption rate was determined by carbon balance. Systems checks were performed before and after a set of tests by the zero and span gas method using calibration gases. The flowmeter was calibrated using a laminar flow element. The ROVER instruments were placed near the driver's seat during idling tests (see Figure 1). The flowmeter module mounting was different for various exhaust pipe configurations. Figure 2 shows the typical horizontal mounting of the flowmeter, which replaced the normal tailpipe on a class-8 truck. ATC technicians adapted to various configurations by making support jigs specific to an exhaust pipe orientation or exhaust pipe size (i.e., smaller flowmeter for Pony Pack™ engine). Since this idling study was a joint effort with ORNL, ORNL staff measured the same pollutants with a separate sampling line that was connected to their own instrumentation.

Figure 1: ROVER system installed on the passenger seat

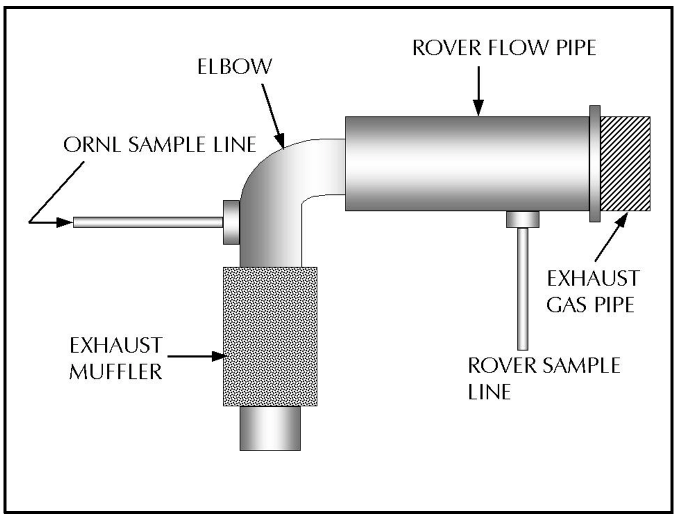

Figure 2: Mounting of ROVER flow pipe / sampling lines
Note: Figure is NOT to scale.

Although PM measurements were obtained by ORNL staff, only the ROVER test data will be presented, with the focus on fuel consumption rates and NOx and CO_2 emissions. ORNL staff will present their PM results in their own SAE paper. *ORNL PM data are not presented in this paper.*

Test Procedure

For the five tests performed during the June 2001 runs, an initial 10 to 15 minute 'warm-up' drive was performed before the idling test began. An ATC driver drove the truck on the highway at about 55 miles per hour, then parked the truck in the climate chamber with the ROVER system fully attached. The ROVER data acquisition program was started once the truck was in motion. The test technician noted when the idling portion of the test began. The chamber technician ensured that the test chamber maintained a steady temperature of 90°F, 0°F, or 65°F, then shut the chamber doors and began the idling test. For safety, the ATC technicians ran flexible exhaust hoses from the flowmeters to ports available in the test chamber to remove unwanted exhaust gases. The same procedure was used for the May 2002 tests, except the warm up drive portion was not done. EPA staff determined from the June 2001 data that the drive portion did not appear to affect the emissions or fuel consumption data.

During the idling tests, the ATC technicians performed routine instrumentation checks every 30 minutes to ensure the highest quality data even under the relatively low exhaust flow rate under idle conditions. This was performed by temporarily applying no-flow conditions to the flowmeter module transducers while recording their outputs. Each pollutant and the volume flow rate during these half-hourly checks show up as zeros or close to zero in the ROVER data files.

All tests for the first phase were performed over a three day period, where two climate controlled chambers were used to test two trucks per day. The order of the tests was randomized to minimize bias in the data collection (i.e., a 1990's truck was tested on the same day as a 1980's truck; two 1990's trucks were not tested the same day). Tests for the second phase were run in a single climate controlled chamber over a three week period. Similar to phase 1, the order of tests was randomized to the extent practicable.

Data Post-processing and Analysis

The ROVER portable emissions measurement system has the capability to create a text file with columns of data for time, HC, CO, CO_2, NOx, engine speed, fuel consumption rate, etc. The data from each test were sampled every second (1 Hz). The ROVER data text files were imported into Microsoft Excel™ for data analysis.

RESULTS AND DISCUSSION

Idling emissions data were collected for nine class-8 heavy duty diesel trucks, two APU Pony Pack™ engines, and one Espar™ DFH. The first part of this section will discuss sample calculations that show how the emissions and emissions reductions were obtained; the second part will discuss the data analyses of the June 2001 testing; the third part will discuss the data analyses of the May 2002 testing.

Sample Calculations

Determining the masses for the pollutants was important for determining the tons of emissions. The ROVER program was set up to determine mass emissions in real time. The gas concentrations in parts per million (ppm) or percentage (%) for the various pollutants, CO, CO_2, NOx, and HC, the measured exhaust gas flow rate, and the gas analyzer transport and response time delays are used. Table 3 shows the densities and other constants used for performing various mass and fuel consumption rate calculations in real time.

Table 3: Constants used in Emissions Calculations

	CO	CO_2	HC	NOx	O_2
Density (g/ft^3)	32.97	51.81	16.33	54.16	37.18

Density of diesel fuel = 3212 g/gal;

$$\text{Weight fraction of C in diesel fuel} = \frac{12.011}{[12.011 + (1.80 \bullet 1.008)]} =$$

= 0.869 from the relation $CH_{1.80}$

Mass of C in 1 gal. of diesel fuel = 3212 g/gal • 0.869 = 2791 g C/gal

An example record from the ROVER data file is shown in Table 4.

Table 4: Sample excerpt from a ROVER Excel Data File

Delta t (s)	1.001	Lambda	9.450
EngineLoad %	0.000	AnalyCorFac	1.015
FUEL RATE G/H	0.900	GPS_Speed(mph)	0.000
ENGINE RPM	1,199	Accel(mph/s)	0.000
OIL TEMP F	209	Road Grade(%)	0.000
Ann_dP ("H2O)L	3.706	Climb Rate(ft/s)	0.000
Ann_dP ("H2O)H	3.734	Altitude(ft)	0.000
Exh_Temp (F)	223.202	Latitude(deg)	0.000
Amb_P ("Hg)	30.237	Longitude(deg)	0.000
Exh_dP ("Hg)	0.008	#_Satellites	0.000
Chamber_T (F)	62.798	PDOP	0.000
Vmix'(scfm)	259.813	T_Heading(deg)	0.000
Vmix_CF	1.000	GPS_Time	
Mode	MT	GPS_Status	Waiting for GPS Time
HC(ppm)	10.000	miles driven	0.000
CO(%)	0.010	HC(mg)	8.373
CO2(%)	1.510	CO(mg)	14.087
O2(%)	18.580	CO2(mg)	3,342.595
NOx(ppm)	239	O2(mg)	29,912
TEMP	82.800	mpg	0.000
Lambda_SO	0.000	mgal	0.332
Lambda(B)	9.320	NOx (mg)	55.306
A/F	136.96		

Values in the white blocks are used in the sample calculation.

For illustration purposes, sample calculations are provided below:

$$\text{Mass of } CO_2 = [ß \bullet \forall \bullet C \bullet dt] / F$$

where:

ß = Density of CO_2 = 51.81 g/ft^3
$\forall$ = Volume Flow Rate = 259.813 ft^3/min
C = CO_2 concentration = 1.51%
F = water condensation in the sample line factor = 1.01
dt = delta time = 1 second

Plugging in the values shown above, yields a mass of CO_2 value equal to 3.342 g = 3342 mg, as shown in Table 4.

Also, using the relation 0.273 grams of C in 1 gram of CO_2 yields the following:

[3.342 g CO_2 • (0.273 g C/1 g CO_2)] / [(2791 g C/1 gal)] =

0.332 mgal = instantaneous milligallons in 1 second.

To determine the gallons per hour fuel consumption rate, a half hour's worth of instantaneous milligallon numbers (not shown in Table 4) are summed up and calculated to yield 1.25 gal/hr.

Data Analyses of June 2001 Tests

As mentioned earlier, the ATC technicians performed routine instrumentation checks every 30 minutes by zeroing the gas analyzer, the MEXA-120, and by checking the zero of the exhaust flowmeter module transducers to detect any drifts in the emission measurement system.

The HC and CO data showed low level emissions that are typical of diesel engines. Although HC and CO data were collected, these data were not relevant to this study, and therefore detailed analyses of HC and CO are not presented in this paper. NOx showed some dynamics during the first few hours of idling, then reached steady state. Therefore, the NOx data were used as the criteria for determining steady state conditions.

In the idling tests, NOx emissions typically exhibited the behavior seen in Figure 3. After about three hours of idling, the emissions reach a steady state condition. When the Kenworth truck was tested the first day, ATC staff ran the test for six hours. It appeared that a three hour idle test would be adequate for determining the steady state emission rates from an idling truck.

CO_2 remains at a fairly constant steady state condition throughout an idling test. However, some tests involving no accessory loads and heater loads showed an initial high CO_2 value in the same manner as the NOx curve in Figure 3 and then reached steady state in about 3 hours. This phenomenon is perhaps due to a 'cold engine

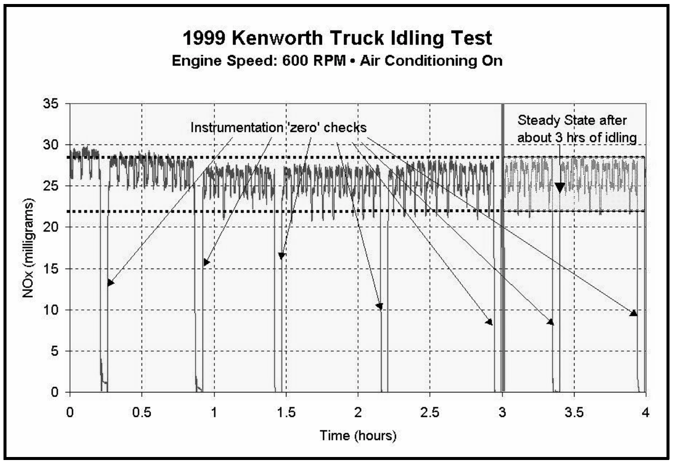

Figure 3: NOx versus time for 1999 Kenworth Truck

starting' scenario where the increased work initially needed to pump the cold engine oil would result in a higher initial CO_2 and then a leveling off (steady state pattern) over time as the engine warms up.

For illustration purposes, Figure 4 shows the detailed steady state NOx patterns for the last hour of the idle test. The emission data (in average grams/hour) for the

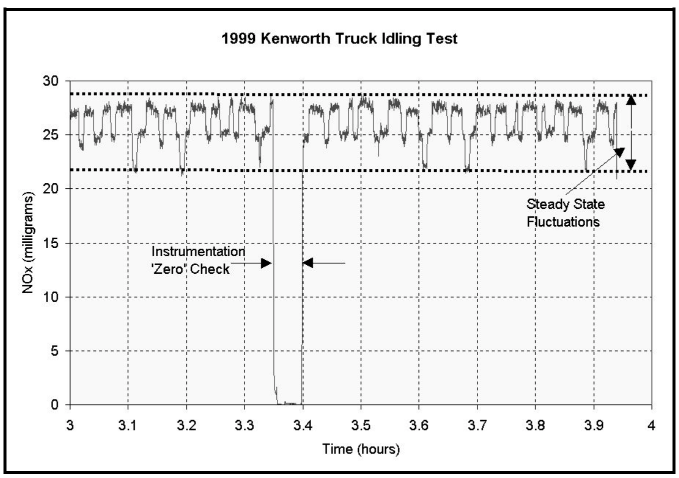

Figure 4: Details/close-up of Figure 3

five trucks are presented in Table 5. As mentioned before, the averaged values were calculated over a steady state portion of the idling data file, typically the last hour or half hour of the idling test.

In Phase 1, the idle speeds were not adjusted for any of the tests, except for the 2000 Volvo. The 2000 Volvo truck has a feature that will shut down the engine if the on-board controls detect that the engine is idling at less than 1000 rpm; therefore, the 2000 Volvo was manually set to idle at 1000 rpm. The idle speed data were obtained either automatically via diagnostic tool port or a direct reading of the dashboard tachometer.

Table 5: Emission Data Summary for 2001 Test Runs

	Idling RPM	NOx g/hr	CO_2 g/hr	NOx* tons/yr	CO_2* tons/yr	gal/ hr
1985 Volvo White	750	19.80	4830	0.05	12.78	0.49
1999 Kenworth	600	81.40	4650	0.22	12.30	0.46
1995 International	600	84.54	4256	0.22	11.26	0.42
2000 Volvo	1000	112.50	8078	0.30	21.37	0.80
1995 Pony Pack Engine	3600	10.13	2199	0.03	5.82	0.22

* These figures were calculated assuming a truck idles at 2400 hrs/year per truck (using the assumptions described in the Introduction section, 8 hr/day, 300 days/yr)

The engine idle speed had a significant effect on the fuel consumption rate, and consequently, CO_2 emissions. The 2000 Volvo truck, which was run at 1000 rpm, produced nearly twice the CO_2 and nearly double the fuel consumption rate compared to a truck run at 600 or 750 rpm. This result is not surprising, considering that if an engine is idling at a faster speed, fuel will be injected into the engine many more times per second, which will lead to a higher fuel consumption rate.

The Pony Pack^{TM} engine is a commercially available idling reduction technology used in thousands of heavy duty diesel trucks in the United States. The Pony Pack^{TM} is a 2-cylinder Kubota^{TM} diesel engine, model Z-200 that practically replaces the main engine's functions during idling periods. It powers the air conditioning, heating, and electrical accessories. The emission data in Table 5 show that there are significant reductions in fuel consumption and emissions when compared to the 1995 International Truck with 1995 Detroit Diesel engine or the other engines tested for this study. There is about an 88% reduction in NOx and 50% reduction in CO_2. When the Pony Pack^{TM} engine emissions are compared to other engines, the reductions can be higher. For example, if a Pony Pack^{TM} is used for idling instead of the stock 2000 Volvo engine, EPA staff estimates a 73% reduction in CO_2 and 90% reduction in NOx could be achieved.

Data Analyses of May 2002 Tests

The May 2002 tests were run in a similar manner to that of the June 2001 tests, except more trucks and idle reducing devices were tested with other variables including heating loads, air conditioning loads, and various RPMs. The following table shows a summary of the test results from the May 2002 tests:

Table 6: Test Results from May 2002

Test #	RPM	chmbr. temp (^oF)	NO_x (g/hr)	CO_2 (g/hr)	gal/hr
1992 Ford Truck with 1992 Caterpillar Engine NCT0893FPB9:					
21	600	0	76.64	5965	0.60
22	1200	0	63.99	11404	1.15
9	600	65	69.41	4653	0.46
10	1200	65	55.76	11342	1.13
11	600	90	75.50	6040	0.60
12	1200	90	69.32	14711	1.47
1998 Freightliner Truck with 1997 Cummins Engine VCE855FJDARA:					
20	1200	0	328.59	12599	1.26
13	600	65	154.49	5348	0.53
14	800	65	164.29	7335	0.73
15	1000	65	163.13	9452	0.94
16	1200	65	199.05	12433	1.26
17	600	90	174.68	6813	0.68
18	1200	90	251.42	16577	1.65
2001 Freightliner Truck with 2000 Detroit Diesel Engine YDDXH12.7EGL:					
Test #	RPM	chmbr. temp (^oF)	NO_x (g/hr)	CO_2 (g/hr)	gal/hr
30	600	0	136.23	6848	0.69
29	1200	0	193.57	10460	1.07
23	600	65	77.69	4392	0.44
24	1200	65	135.31	9787	0.98
25	600	90	94.36	4787	0.48
26	1200	90	186.95	12090	1.21
1997 International Truck with 1997 Caterpillar Engine VCP893EZDARX:					
34	700	0	137.02	7099	0.71
33	1100	0	196.76	10232	1.02
31	700	65	146.01	5596	0.55
32	1100	65	214.62	10043	0.99
36	700	90	174.17	7262	0.72
37	1100	90	267.27	13575	1.34

The test numbers denote the sequence in which the tests were run. Test instrumentation issues were worked out early in the testing by running triplicate identical tests to assure good test repeatability as can be seen with test numbers 1, 2, and 4 (see double lined entries in Table 6).

Table 6 (continued):

Test #	RPM	chmbr. temp (^oF)	NO_x (g/hr)	CO_2 (g/hr)	gal/hr
1999 Volvo Truck with 1999 Detroit Diesel Engine XDDXH12.7EGL:					
6	600	0	54.83	5878	0.61
7	1200	0	170.28	10877	1.17
1	600	65	80.98	4102	0.41
2	600	65	86.64	3968	0.40
4	600	65	83.24	3915	0.39
3	1200	65	240.98	9251	0.92
5	600	90	104.58	5042	0.50
8	1200	90	288.42	11679	1.16
2000 Pony Pack APU Engine YKBXL.719KCB (for 2001 Freightliner Truck):					
28	3600	0	7.27	2053	0.20
27	3600	90	10.01	2353	0.23
Espar Direct Fired Heater Model D1LC (for 1997 International Truck):					
38	N/A	30	0.21	402	0.04

NOTES: "Chmbr. temp" = Chamber Temperature
"RPM" = Engine idling RPM set during a three hour test
Tests for the 1997 International truck were run at 700 and 1100 RPMs since these were the high and low engine speeds available.
Test with 1998 Freightliner at 0 ^oF was omitted due to instrumentation problems (excessive freezing on the sample line).
Tests 1, 2, and 4 are repeat tests intended to demonstrate repeatability of test instrumentation (outlined in double lines in this table).

For tests 1, 2, and 4, the standard deviations for NOx, CO2, and fuel consumption were 4.85 g/hr, 96 g/hr, and 0.01 gal/hr, respectively. The coefficients of variation (standard deviation divided by the mean) for NOx, CO2, and fuel consumption were 0.06, 0.02, and 0.025. These values indicate low variability and good test repeatability.

Several tests on the 1998 Freightliner truck showed a good linear relationship between fuel consumption rate and engine rpm. Upon analyzing the data at the various rpm, EPA staff concluded that running tests on a high and low rpm would be adequate to predict intermediate fuel consumption rates at intermediate rpm's. Figure 5 shows a graphical representation of the 1998 Freightliner truck data shown in Table 6. An R^2 value of 0.99 shows a strong linear relationship. All tests in Figure 5 were run without any accessories active (at 65^{o}F). Different accessories produced different NOx emission patterns during the idling tests. Tests with no accessories active or heater active showed flat line responses as shown in Figure 6.

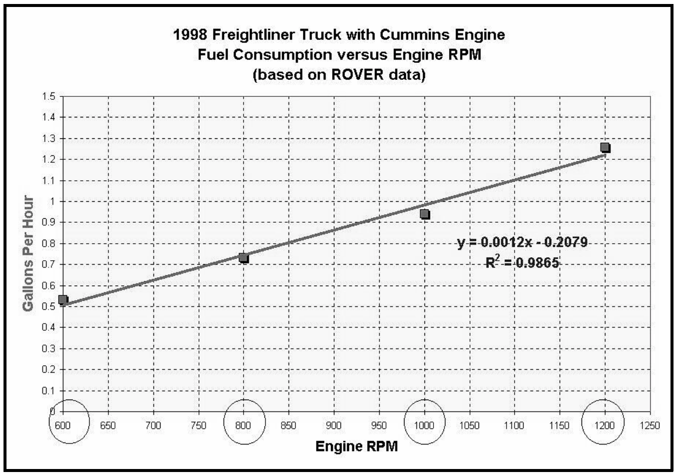

Figure 5: Linear relation between gal/hr and rpm

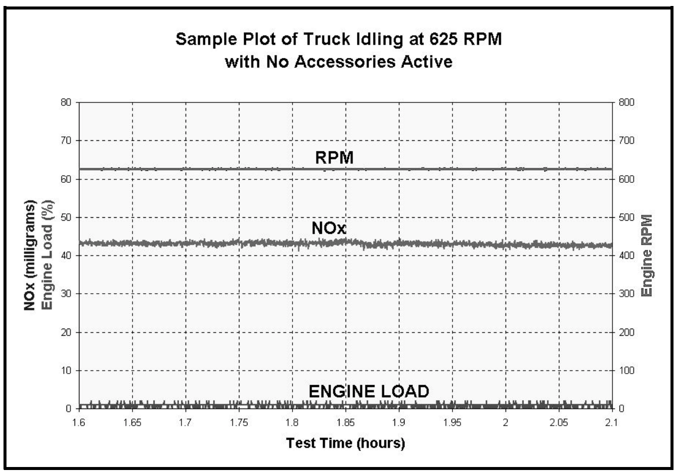

Figure 6: Example Plot with No Accessories Active

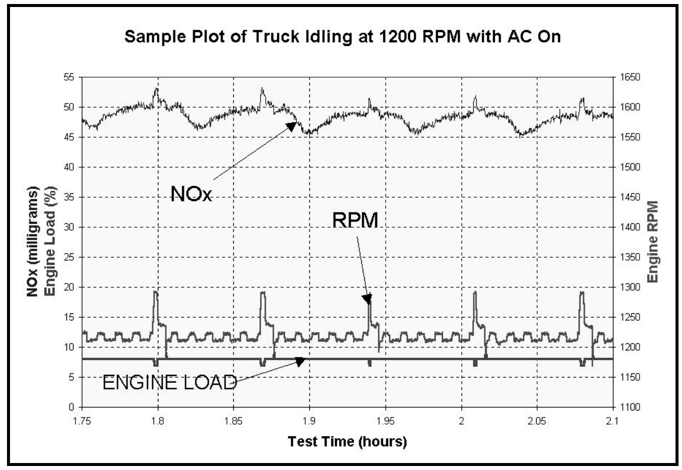

Figure 7: Example Plot of Air Conditioning Test

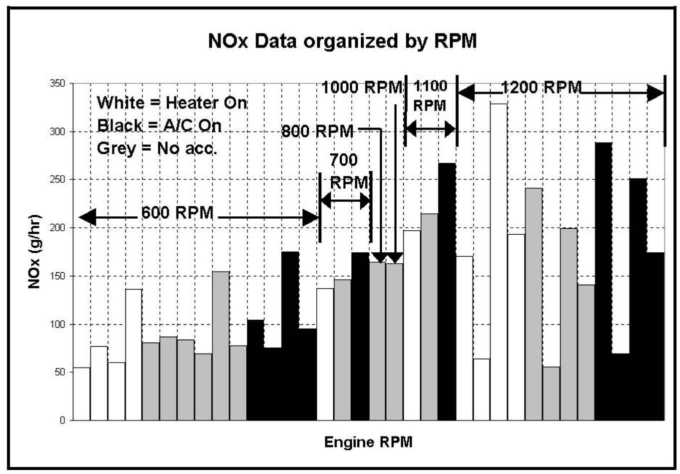

Figure 8: NOx data sorted by RPM for 2002 Tests

Air conditioning tests, however, showed cyclical patterns, which is caused by the engine fan and the air conditioner electromagnetic clutch engaging during the tests (see Figure 7). Furthermore, Figure 7 shows that the engine rpm, engine load, and NOx emissions are affected by the air conditioner compressor load. The NOx, rpm, and load spikes and peaks appear to occur at the same time. These spikes and peaks produce an additive effect on the NOx emission rates. As discussed in the June 2001 data section, higher rpm's will produce higher emissions and fuel consumption rates as evidenced in the data presented in Table 6.

Figure 8 shows all of the average NOx data in grams per hour for the 2002 tests. Note that there is a general trend where NOx increases with chamber temperature and RPM. The data in Figure 8 are also presented in Table 6. The occasional low NOx values are from the 1992 Ford Truck with a Caterpillar engine. This truck appears to have the lowest NOx values and seems least affected by engine RPM or ambient temperature or accessories active.

Clearly, air conditioning tests will produce higher NOx values, especially with the additive cyclical NOx emission patterns and higher engine load from the air conditioner compressor.

The matrix of tests run during 2002 showed a wide range of fuel consumption and emissions results by varying engine age, engine rpm, and ambient temperature (accessories on or off). Table 7 summarizes the high, low, and average values.

Table 7: High, Low, and Average Emissions and Fuel Consumption Rates for 2002 Test Data

	NOx (g/hr)	CO_2 (g/hr)	gal/hr
ARITHMETIC MEAN FOR ALL TESTS			
High Value	329	16,578	1.65
LowValue	55	3,915	0.39
Average Value	144	8,224	0.82
Standard Deviation	72	3571	0.40
Coefficient of Variation	0.5	0.43	0.43
Low RPM avg. (600 - 800 rpm)	114	5805	0.58
High RPM avg. (1000 - 1200 rpm)	190	11815	1.18
WEIGHTED AVERAGE VALUES (60% High RPM, 40% Low RPM):			
Weighted Average Value:	160	9411	0.94
WEIGHTED AVERAGE VALUES (70% High RPM, 30% Low RPM):			
Weighted Average Value:	167	10012	1.00

As it turns out, the average fuel consumption rate is the same as the highest rate obtained from the 2001 testing. The average NOx of 144 g/hr, however is somewhat higher than the 112 g/hr obtained from the 2001 testing, which seems reasonable considering tests at higher rpms such as 1200 rpm were performed. One should keep in mind that the average values in Table 7 are calculated with *over 30 unique test scenarios that span extreme ambient temperatures, engine rpms, and parasitic loads (A/C and heating)*, which would explain the coefficients of variation in the 0.4 to 0.5 range.

It is general practice to idle the engine at 1000 rpm or higher when heavy accessory loads are present. Truckers can reasonably be expected to operate their heaters on days when the temperature drops below 50°F and to operate their air conditioning on days when temperatures exceed 70°F. National Oceanic and Atmospheric Administration (NOAA) temperature data indicate that these temperature ranges can be expected to occur nationwide between four and nine months of the year (NOAA, 2000). Operation of accessory loads would occur during these months.

With that said, for illustration purposes only, weighted average values were calculated in addition to the overall arithmetic mean values, to reflect use of accessory loads. Table 7 shows that with the high rpm tests weighted at 60% and low rpm tests weighted at 40%, the weighted average NOx value is 160 g/hr. If the high rpm weighting factor is increased to 70% high rpm, with a 30% low rpm, the weighted NOx is 167 g/hr. These are only example weighted averages. However, EPA staff conservatively estimate that on average, an idling class-8 truck can emit 144 g/hr of NOx based on the data collected in this study.

Emissions and Fuel Consumption Reductions Achievable by Using Idle Reducing Devices

Several types of technologies exist that will effectively reduce long-duration idling. EPA maintains a list of idle reduction technologies that can be accessed at the following website: http://www.epa.gov/otaq/retrofit/idlingtech.htm. EPA makes no claims as to the effectiveness or operation of these products, and the list is for informational purposes only. Two idle technologies were selected to determine the emissions associated with these products, and their potential emission reductions when compared to baseline idling emissions from the test vehicles. One technology, an auxiliary power unit by Pony Pack, Inc. has the ability to provide heat, air conditioning, and electrical power. The other technology is a direct fired heater by Espar, Inc., which provides heat only. These two products were selected for their ability to provide air conditioning and/or heat. While other similar products exist on EPA's list of technologies, these two were selected arbitrarily.

The following discussion compares the idle reduction device to the truck to which that device is attached. For the direct fired heater (DFH), NOx emission rates and fuel consumption rates from the 1997 International Truck with Caterpillar engine are compared to the DFH. With the DFH producing 0.21 g/hr of NOx and the Caterpillar engine emitting 137 to 197 g/hr (700 to 1100 rpm, respectively at a chamber temperature of 0°F with the main engine heater on), a 99% reduction in NOx appears to be achievable. Similarly, Table 8 shows percent reductions achievable from a DFH or an APU.

The data from the May 2002 testing shows results comparable to those obtained in June 2001. The 1995 APU was capable of reducing NOx by 88% and CO_2 by 50%, whereas a 2000 APU was capable of reducing NOx by 89 to 96% and CO_2 by 52 to 81%.

Although the data obtained from June 2001 provided a glimpse of the idling data characteristics, EPA staff based their data analyses and emissions estimates on the May 2002 data, which provided a more comprehensive and consistent set of data. Nevertheless, the data from 2001 and 2002 are comparable.

Table 8: Percent Reductions Achievable with the Use of an Idle Reducing Device

1997 International Truck with Caterpillar Engine with the **truck heater on**			
	gal/hr	NOx (g/hr)	CO_2 (g/hr)
Truck @ 700 rpm	0.71	137	7100
Truck @ 1100 rpm	1.02	197	10232
DFH	**0.04**	**0.21**	**402**
Percent Reduction	94-96%	99%	94-96%
2001 Freightliner Truck with Detroit Diesel Engine with the **truck heater on**			
	gal/hr	NOx (g/hr)	CO_2 (g/hr)
Truck @ 600 rpm	0.69	136	6848
Truck @ 1200 rpm	1.07	194	10640
APU w/ heater on	**0.20**	**7.3**	**2053**
Percent Reduction	71-81%	94-96%	71-81%
2001 Freightliner Truck with Detroit Diesel Engine with the **truck air conditioning on**			
	gal/hr	NOx (g/hr)	CO_2 (g/hr)
Truck @ 600 rpm	0.48	95	4787
Truck @ 1200 rpm	1.21	174	12090
APU w/ AC on	**0.23**	**10.0**	**2353**
Percent Reduction	52-80%	89-94%	52-80%

Using the data in Tables 7 and 8 it is possible, with some assumptions about the idling characteristics of the fleet, to make estimates of the idling emissions of the nation's truck fleet. As an example, if the fleet consists of 500,000 trucks and those trucks idle 8 hours per day, 300 days per year while consuming 0.8 gal of fuel per hour then those trucks produce 10.9 million tons of CO2 per year (21.7 tons/year per truck) and 190,476 tons of NOX per year (0.38 tons/year per truck). Under this example, those trucks would consume 960 million gallons of diesel fuel while idling.

CONCLUSION

The purpose of EPA's idling test program was to closely examine long-duration idling emissions on a diverse group of heavy duty trucks under various engine speeds, ambient temperatures, and accessory loads. Prior to this test program, long-duration idling tests had not been conducted. EPA and other organizations and institutions have examined idling for brief periods of time, but these tests did not reflect the more realistic long-duration idling periods.

Based on the emissions and fuel consumption data generated from this study, the test data showed that (a) on average, a class-8 truck could emit 144 g/hr of NOX and 8224 g/hr of CO_2, and could consume about 0.82 gal/hr of diesel fuel and (b) the use of idle reduction technologies can reduce fuel consumption and emissions significantly.

The idling test program supports EPA's continued commitment in working with the trucking industry and its stakeholders to reduce idling. To date, EPA has organized workshops, funded demonstration projects, and created a grant program to assist trucking companies. Future plans include identifying idling emissions within mobile models and inventories, and creating incentives for states to reduce idling.

REFERENCES

Avallone, Eugene A. and Theodore Baumeister III, *Marks' Standard Handbook for Mechanical Engineers Ninth Edition*, McGraw-Hill Publishers, 1987

Brodrick, C.J. et al, *Potential Benefits of Utilizing Fuel Cell Auxiliary Power Units in Lieu of Heavy Duty Truck Engine Idling, Institute of Transportation Studies*, University of California - Davis, 2001.

National Archives and Records Administration (NARA), *Code of Federal Regulations Title 40 Part 86: Control of Emissions from New and In-Use Highway Vehicles and Engines*, Office of the Federal Register, July 2001.

National Energy Policy Development Group, *National Energy Policy*, President of the United States of America, May 2001.

National Oceanic and Atmospheric Administration, National Climate Data Center, U.S. Climatological Averages and Normals, Normal Daily Maximum and Minimum Temperatures, Degrees F (1971 - 2000); Calculated by month (January - December) for major metropolitan areas, 2000.

Schenk, Charles R., Joseph F. McDonald, and Christopher A. Laroo, *High Efficiency NOx and PM Exhaust Emission Control For Heavy Duty On-Highway Engines - Part Two.* SAE Paper Number: 2001-01-3619, Society of Automotive Engineers International, 2001.

Stodolsky, Frank, Linda Gaines et al, *Analysis of Technology Options to Reduce Fuel Consumption of Idling Trucks*, Center for Transportation Research, Argonne National Laboratory, Paper No. ANL/ESD-43, 2000.

U.S. Census Bureau, *VIUS 1997, Vehicle Inventory and Use Survey*, Department of Commerce, Washington, D.C. 1997.

U.S. Environmental Protection Agency, Office of Transportation and Air Quality Web site; URL address: www.epa.gov/otaq