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AN ESTIMATE OF THE EMISSIONS OF GAS-PHASE TOXIC COMPOUNDS FROM HEAVY-DUTY DIESEL POWERED VEHICLES

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Abstract

Diesel exhaust is a complex mixture of hundreds of gas-phase and particle bound compounds. Recently there has been an increased interest in gas-phase toxic emissions from mobile sources by EPA and other regulatory agencies. Most of this effort has been directed toward gasoline powered vehicles and little effort has been given to quantifying the levels of gas-phase toxic emissions from diesel vehicles. Quantifying the emission rates of gas-phase toxic compounds from diesel powered vehicles is critical in understanding the overall impact of these vehicles to public health and the positive impact that new fuels, emission controls, and new technology will have on reducing these emissions. In this study we measured gas-phase air toxic emissions from a fleet of in-use class 8-diesel trucks. The vehicles were run on an ultra low sulfur diesel (ULSD) fuel and measurements were made over the 4 modes California Air Resource Board (CARB) Heavy Heavy-Duty Diesel Truck (HHDDT) driving cycles, including cold start/idle, creep, transient, and cruise mode. All trucks were tested using CE-CERT's HDD on-road mobile lab.

Experimental Procedures

- All vehicles were tested over a heavy-heavy-duty diesel truck (HHDDT) test cycle developed by California Air Resource Board to obtain mass emission rates
- Tailpipe emissions of total hydrocarbon (THC), CO, NOx, and PM were measured following the Code of Federal Regulations.
- Samples for HC speciation were collected in 8L black Tedlar gas chromatographs (GC) bags and analyzed by GC in 4 hours.
- Aldehydes and ketones emissions were collected onto dinitrophenyl-hydrazine (DNPH)-coated silica gel cartridges. The DNPH cartridges were analyzed by high performance liquid chromatography (HPLC).

Selected fuel properties of ULSD in comparing to that of in-use California reformulated diesel (CARB) fuel and national average

	Cetane Index	Total Aromatics vol %	Polycyclic Aromatics mass%	T10 °F	T50 °F	T90 °F	Sulfur ppm	Specific Gravity
ULSD	44.9	19.5	1.98	384	494	619	10	0.824
CARB*	51.3	22.9	3.78	-	908	630	72	0.839
National average min CA and AZ**	45	24	10	-	-	-	330	0.850

*Zhu et al. "An Estimate of the Emissions of Toxic Air Contaminants for Medium-Duty Diesel Powered Vehicles". A & WMA 96th annual conference, 2002.
**CARB, "Staff Review of the Emission Benefits of California's Diesel Fuel Program", Fuels Section, Criteria Pollutants Branch, Stationary Source Division, California Air Resources Board. March 2003.

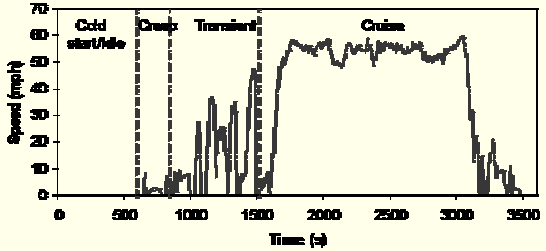
Description of Test Vehicles

Truck #	Model	Tractor Year	GVW lb	Odometer mi	Year	Engine Model	Rated Power at RPM Hp rpm
1	FTL D120	2001	14700	8000	2000	CAT C-10	475 2100
2	Intrnl 9800 Elite	1997	14860	442874	1997	Cummins ISM L-330	330 1800
3	FTL D120	1997	47240	644750	1998	DD/C-60	360/400 1800
4	FTL D120	1997	19520	613786	1997	Cummins M11	370/435 1800
5	FTL C120	1997	18840	583845	1997	Cummins M11	370/435 1800
6	FTL C120	1998	17840	440454	1997	DD/C-60	370/430 1800
7	FTL D120	1999	18840	480340	1998	DD/C-60	470 2100
8	FTL D120	1999	18840	460854	1998	DD/C-60	360 1800

FTL: Freightliner; DD: Detroit diesel; CAT: Caterpillar

CE-CERT's HDD mobile laboratory **Mobile laboratory interior**

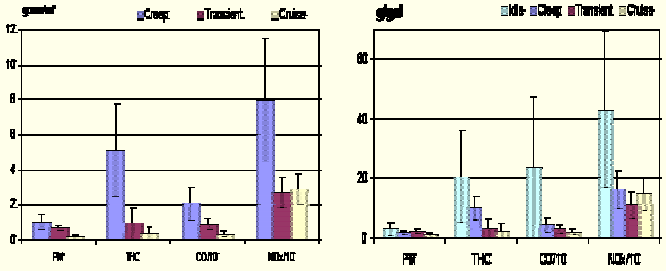
Four-phase ARB heavy-heavy-duty truck combined emission test cycle



Agrawal, A.; Carlock, M.; Maldonado, H. "Development of Heavey-Duty Vehicle Chassis Dynamometer Driving Cycles", 12th CRC On-Road Vehicle Emissions Workshop, San Diego, California, April 15-17, 2002

Emission Test Results

Regulated emissions for testing fleet based on distance and fuel consumption



Emission rates of gas phase air toxics based on distance and fuel consumption

Compounds	Creep mg/mi	Transient mg/mi	Cruise mg/mi	Idle mg/gal	Creep mg/gal	Transient mg/gal	Cruise mg/gal
Acetaldehyde	288	18	13	790	840	87	88
Acrolein	410	20	12	1470	915	87	69
Benzene	28	8	2	140	84	28	11
1,3-butadiene	27	6	2	124	83	28	11
Ethylbenzene	5	1	1	11	6	5	8
Formaldehyde	383	48	33	6833	1898	160	199
n-Hexane	95	5	1	25	96	16	4
Naphthalene	8	4	2	28	16	13	12
Xylene	12	3	2	24	23	13	11
Toluene	24	7	3	68	46	28	19
o-Xylene(a)	6	4	1	9	14	17	5
m&p-Xylene	14	8	2	21	28	24	14

Relative lifetime cancer risks for different operating modes

Compound	Cancer unit risk* (mg/m³)⁻¹	Relative lifetime cancer risk (mg/mi) Creep	Transient	Cruise
Acetaldehyde	2.70E-06	1.11	0.06	0.03
Benzene	2.90E-05	0.89	0.19	0.06
1,3-Butadiene	1.70E-04	4.83	0.96	0.29
Formaldehyde	6.00E-06	5.72	0.28	0.20
Total gas phase relative risk		12.16	1.48	0.57
PM	3.00E-04	300.8	180.6	80.7
Total relative cancer risk		317.8	182.1	87.2
% of gas phase cancer risk		4%	1%	1%
% of PM cancer risk		96%	99%	99%

a: Consolidated table of OEHHA/ARB approved risk assessment health values, March 2002

Conclusion

• Emission rates of all pollutants are highly dependent on test cycle. Cold start/idle and creep phase of HHDDT provided significantly higher emission rates for PM, THC, CO, NO_x and toxics compared to transient and cruise phases.

•Creep phase provided significantly higher relative lifetime cancer risk in comparison to transient and cruise phases. Every mile driving with creep mode provides a risk from gas-phase toxic compounds that is equivalent to driving 8 miles in the transient phase or driving 21 miles in cruise phase.

• Of the gas-phase MSATs, formaldehyde had the highest emissions for each of the vehicle/driving cycle combinations, with acetaldehyde having the second-highest emissions. Formaldehyde also was found to be the most prevalent carbonyl and accounted for about 39 to 50% of total identified carbonyl emissions.

• In gas-phase TACs, 1,3-butadiene is the greatest contributor to relative lifetime cancer risk for all vehicles because of its high unit risk factor, followed by formaldehyde. The results show that 1,3-butadiene contributes approximately 51% to total gas-phase relative risk for all vehicles.

•Overall relative lifetime cancer risk from gas-phase toxics much lower than that from PM. In average PM contributed approximately 96% to 99% to the total relative lifetime cancer risk, while gas phase toxics account for approximately 1% to 4%.