

Supplemental Information
for
Gasoline Direct Injection Engine Emissions of OC and EC:
Laboratory Comparisons with Port Fuel Injection Engine

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Test cycles information

Table S1. Parameters and phases of FTP-75, FTP-72 and US06 cycle

Cycles	Distance traveled	Average speed	Maximum speed	Included phases
FTP-75	11.04 miles (17.77 km)	21.2 mph (34.12 km/h)	56.7 mph (91.25 km/h)	1. Cold start transient phase (ambient temperature 20-30°C), 0-505 s, 2. Stabilized phase, 506-1372 s 3. Hot soak (min 540 s, max 660 s) 4. Hot start transient phase, 0-505 s
FTP-72	7.5 miles (12.07 km)	19.6 mph (31.5 km/h)	56.7 mph (91.25 km/h)	1. Hot start transient phase, 0-505 s. 2. Stabilized phase, 506-1372 s
US06	8.01 mile (12.8 km)	48.4 miles/h (77.9 km/h)	80.3 miles/h (129.2 km/h)	1. Hot start phase

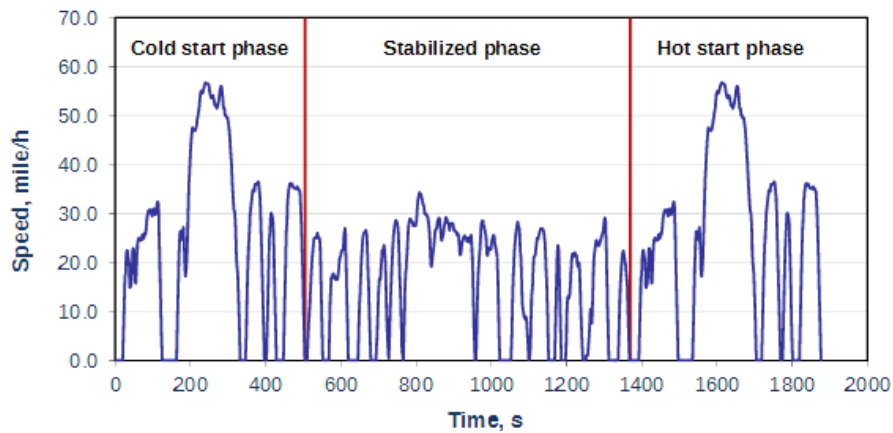


Figure S1. Vehicle speed trace for the FTP-75 drive cycle (from dieselnets)

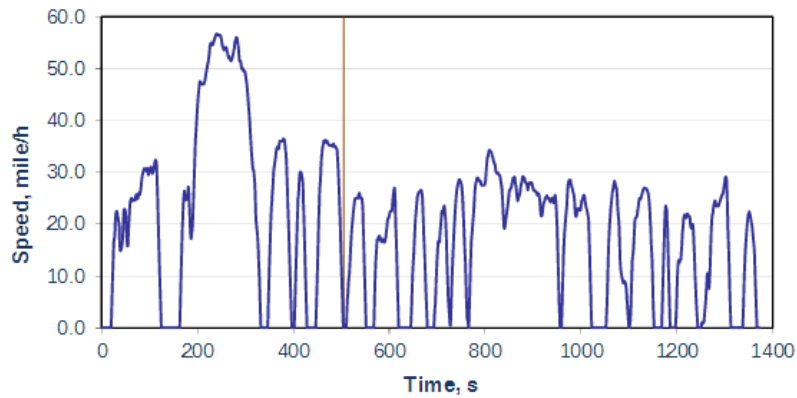


Figure S2. Vehicle speed trace for the FTP-72 drive cycle (from dieselnets)

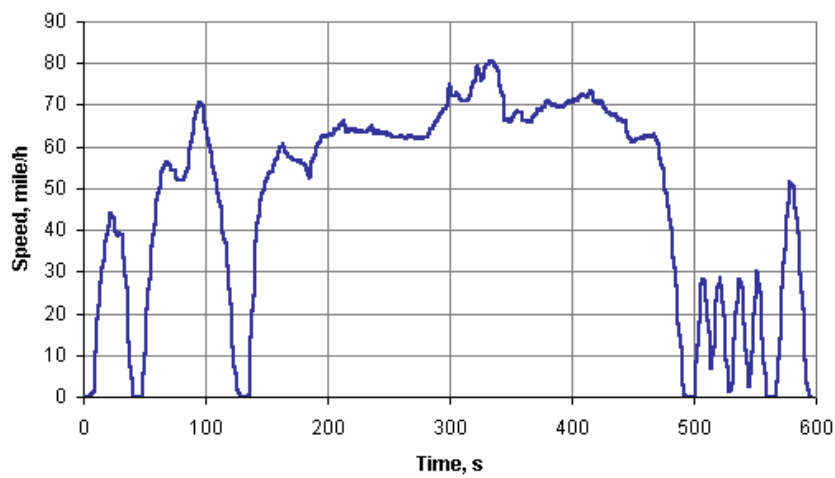


Figure S3. Vehicle speed trace for the US06 drive cycle¹

Regular gaseous pollutants measurement

Carbon dioxide (CO₂) and carbon monoxide (CO) were measured by the Horiba Non-Dispersive Infrared Absorption Instruments (AIA-210 and AIA-210LE). NO_x were detected using the California Analytical heated Chemiluminescence Instrument (400-HCLD). THC was measured by a California Analytical heated Flame Ionization Detection Instrument (300M-HFID) (Chan et al., 2016). The results of vehicle settings shown in Table S2, including standard deviations of repeated tests.

Table S2. Gaseous pollutant concentrations and difference among repeat measurements.

Test cycle	Vehicle	CO	CO ₂	NO _x	THC
FTP-75	GDI	1.29	393	0.02	0.05
	GDI w/GPF	0.7	376	0.01	0.07
	PFI	0.30	418	0.04	0.07
FTP-72	GDI	0.58±29%	350 ±3%	0.01±0%	0.01±0%
	GDI w/GPF	0.26±10%	343±2%	0.02±50%	0.01±0%
	PFI	0.31±23%	377±2%	0.02±33%	0.02±33%
US06	GDI	2.51±11%	331±1%	0.03±20%	0.02±0%
	GDI w/GPF	1.28	319	0.03	0.02
	PFI	0.42±11%	350±0%	0.03±20%	0.02±0%

Protocols for OC/EC measurement

Table S3. Experimental parameters of the three OC/EC protocols used in this study

Method carrier gas	Carbon fraction	Temperature of the optical protocols		
		IMPROVE TOR/TOT	NIOSH TOT	ECT9
He	OC1	120	250	550
He	OC2	250	500	870
He	OC3	450	650	
He	OC4	550	850	
O ₂ /He	EC1	550 ^a	650 ^a	900 ^b
O ₂ /He	EC2	700 ^a	750 ^a	
O ₂ /He	EC3	800 ^a	850 ^a	

^a 2%O₂/98%He

^b 10%O₂/90%He

In all three protocols shown in Table S3 pyrolyzed organic carbon (POC) is formed during heating in the inert atmosphere. The amount of POC is defined as the carbon combusted after the initial introduction of oxygen and before the laser reflectance or transmission signal achieves its original value¹⁵. For IMPROVE and NIOSH, OC is defined as OC1+OC2+OC3+OC4+POC and EC is defined as EC1+EC2+EC3-POC. For EnCan, OC is defined as OC1+OC2+POC and EC is defined as EC1-POC. It has to be noted that the wavelength for the transmittance signals in the instruments used for

the IMPROVE (DRI model 2001 carbon analyzer) and NIOSH (Sunset Laboratory, Inc., Forest Grove, OR) method are different, at 632 nm and 678 nm, respectively. Moreover, the DRI analyzer changes temperature only after the previous peak in carbon (i.e., methane detected by the FID) completely evolves, while the Sunset analyzer changes temperature at fixed times. The EnCan protocol, which uses the Sunset Labs carbon analyzer with transmission, also dwells longer at each temperature to allow all carbon to evolve before increasing temperature to the next step in the protocol.

The method detection limit (MDL) for all three methods is estimated in this study using the standard deviation among the blank quartz filters ($3 \times$ standard deviation of the blanks) based upon the 99% confidence level. The detection limit of OC was 0.30, 0.23 and $0.49 \mu\text{g}/\text{cm}^2$, and of EC it was 0.02, 0.19 and $0.05 \mu\text{g}/\text{cm}^2$, for IMPROVE, NIOSH and EnCan, respectively. Our samples were generally well above MDL, but a small portion of samples were very low and comparable with blank results, thus blank corrections were not undertaken.

OC/EC Measurement results

Table S4 Comparison of the OC/EC emission factors determined using the three different protocols ($\mu\text{gC}/\text{km}$)

Cycles	Measurement protocols	GDI		GDI+GPF		PFI	
		OC	EC	OC	EC	OC	EC
FTP-75	IM_TOR	315	5066	336	87	191	349
	NI	352	4705	315	64	221	307
	ECT9	266	4816	353	99	227	307
FTP-72	IM_TOR	250	685	379	0	257	0
	NI	259	660	461	0	340	0
	ECT9	260	665	484	30	257	57

	IM_TOR	1251	3416	595	0	3548	636
US06	NI	1404	2679	467	0	3520	289
	ECT9	1710	2704	620	29	3674	305

Table S5 OC1 emissions in the test settings measured by IMPROVE method

($\mu\text{gC}/\text{km}$)

Cycles	GDI	GDI+GPF	PFI
FTP-75	1.0	66.6	30.4
FTP-72	1.4	94.2	47.8
US06	235.5	269.9	389.0

References

Dieselnet. The driving test cycle figures were from dieselnet.

<https://www.dieselnet.com/>

Chan, T. W., Saffaripour, M., Liu, F., Hendren, J., Thomson, K.A., Kubsh, J., Brezny, R., Rideout, G. (2016). Characterization of Real-Time Particle Emissions from a Gasoline Direct Injection Vehicle Equipped with a Catalyzed Gasoline Particulate Filter During Filter Regeneration. *Emiss. Control Sci. Technol.* 2, 75-88.