REAL-TIME AND FILTER-BASED BLACK CARBON MEASUREMENTS FOR VEHICLE EMISSIONS

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INTRODUCTION

Black carbon (BC) emissions from light duty vehicles (LDVs) and BC measurement methods were investigated. BC is the carbonaceous material which absorbs light. As reported by IPCC, BC is a potent climate forcing agent and the second largest contributor to global warming. For emission control strategy development, there is a need to quantify BC emissions from LDVs using PFI and GDI technologies. Meanwhile, limited information is available about the comparability of BC measurement methodologies when applied to LDV emissions.

In this study, we employed four real-time instruments and one filter-based instrument , measuring BC emissions from LDV chassis dynamometer tests. The results of the BC measurement methods were compared to the elemental carbon (EC) based on the IMPROVE_A TOR thermal-optical carbon analysis. LDV BC emission rates and emission profiles are also presented.

EXPERIMENTAL METHOD

Sampling: Vehicle exhaust was directed to and diluted in a Constant Volume System (CVS) tunnel. A small stream of the diluted exhaust was then split to filter assemblies for PM gravimetric and EC determinations, and to the real time instruments for measurement in concentration.

Sample Analysis: Particulate matter was collected on Teflon filters following 40 CFR Part 1065 for PM mass analysis. PM was also collected on Quartz filters for OC/EC mass analysis. These Teflon and Quartz filters were also used for BC mass analysis.

Vehicle: Four Gasoline Direct Injection (GDI) vehicles and two Port Fuel Injection (PFI) vehicles were tested.

Fuel: Three types of fuels were used: Phase II Certification Fuel that contains MTBE; E6; and E10 market fuel. Fuel properties are listed in Fan *et al*. (CRC Poster 2011).

Test Cycle: FTP-75 (reported here), UC, and US06 were used for the vehicle tests.

INSTRUMENTS

Two light attenuation instruments, two photoacoustic instruments, and one optical transmissometer, were used to measure BC from vehicle emissions. The IMPROVE_A TOR thermal-optical method was used to quantify EC. Table 1 shows the measurement principles and key parameters of the instruments. It is important to note that, as indicated in the literature, measured BC mass may be dependent on the measurement principles and instrument calibrations.

Analyte	Instrument	Operating Principle	Time Resolution
PM	Mettler Toledo UMX 2 Microbalance	Weighing	Time Integrated
EC	DRI Thermal/Optical Carbon Analyzer	Thermal/Optical	Time Integrated
BC	Magee Optical Transmissometer OT21	Light Attenuation	Time Integrated
BC	AVL 483 Micro Soot Sensor AVL MSS	Photoacoustic	Real Time/ 1 sec
BC	Droplet Inc. PASS-1	Photoacoustic	Real Time/ 1 sec
BC	Magee AE22 Aethalometer	Light Attenuation	Real Time/ 5 sec
BC	Magee AE51 Aethalometer	Light Attenuation	Real Time/ 1 sec

Table 1. List of real time and filter-based instruments

DATA ANALYSIS

Filter-based masses and real time concentrations were converted to mg/phase and mg/mi for data reduction and analysis. The available data on vehicle types and test fuels are listed in Table 2.

Vehicel	Type	Odometer	Fuel		
			MTBE	E6	E10
BMW335	Spray-GDI	2,409	x	x	
BMW750	Spray-GDI	293	x	x	
VOLK	Wall-GDI	76	x	x	x
PORS	Wall-GDI	124,558		x	
GM	PFI	20,849	x	x	
NISS	PFI	28,725		x	x

Table 2. Vehicle tests conducted for each vehicle and fuel.

BC CORRELATION TO EC MASS

The BC measured by these five instruments showed good correlation with EC, as shown in Figure 1.

- R^2>0.75;
- The mass ratios varied. On average:
  - The difference between the BC masses measured by the AVL MSS and AE51 and the EC masses is less than 5%;
  - OT21 obtained BC masses on both Teflon and Quartz filters deviated from the EC masses by less than 20%;
  - In contrast, the Droplet PASS and AE 22 measurements deviated from the EC measurements by more than 30%.

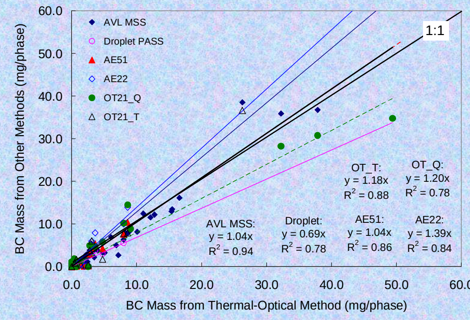

Fig.1. Comparisons of BC mass to thermal-optical EC mass for each test phase. OT21_Q denotes for OT21 measurements on Quartz filters and OT21_T for Teflon filters.

BC MASS AND BC/PM RATIO BASED ON VEHICLE, FUEL, AND TEST CYCLE

The BC masses and BC/PM mass fractions were affected by vehicle type, fuel, and test cycle.

- GDI vehicles, on average had higher BC emissions than PFI vehicles: GDI *vs.* PFI: 1.23±0.77 *vs.* 0.37±0.17 mg/mi.
- BC emissions from the spray-guided BMW 750I GDI vehicles are about twice of those from the spray-guided BMW 350I GDI, Figure 2.
- Impacts of fuel and test cycle (UC and US06) on BC emissions were observed from preliminary results.
- The BC/PM ratios based on EC and AVL MSS are 70±10% and 67±5%, respectively, as shown in Figure 3.

Direct BC measurement may be necessary to quantify BC emissions from LDV.

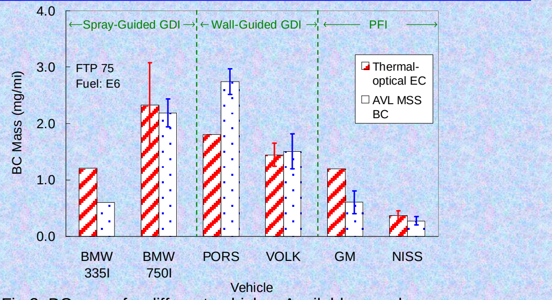

Fig.2. BC mass for different vehicles. Available error bars represent the 95% confidence intervals for the BC masses.

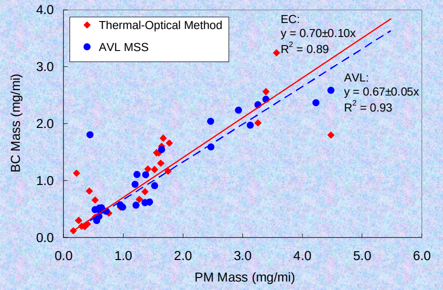

Fig.3 Overall BC/PM mass fractions measured from the thermal-optical method and the AVL MSS with 95% confidence intervals. The data here included results for GDI and PFI vehicles and for all fuels.

CONCLUSION

- The data showed good correlation, comparing results obtained by the BC measurement instruments to the EC by the IMPROVE_A thermal-optical method. On average, the AVL MSS, AE51, and OT21 provided reasonable BC masses (<20%). However, the AE 22 and Droplet units obtained substantially different BC masses (>30%), which may be due to the instrument calibration methods.
- BC masses, as well as the BC/PM mass fractions, are dependent on vehicle type, fuel, test cycle, and choice of BC measurement principle. On average, GDI vehicles emitted more BC masses than PFI vehicles.
- Direct BC measurement may be necessary for emissions from LDV.
- Based on the mixed vehicle/fuel data in this study, the overall BC/PM mass fractions are about 0.70. The derived fractions were dominated by the GDI vehicles as they have higher BC emissions.

DISCLAIMER

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