TG1: Real-time Instrument for Diesel Exhaust Particulate Measurement

Sreenath B. Gupta
Sgupta@anl.gov
Argonne National Laboratory, USA 60439

Fig. 1 Panoramic view of prototype TG1

Slide 2: gives the terminology used in the presentation.

Slide 3: A survey of available instrumentation in the US market shows that real-time quantitative measurements of particulate emissions to be elusive. The most promising instrument appeared to be the Tapered Element Oscillating Microbalance (TEOM).

Slide 4: In comparison, Laser Induced Incandescence (LII), a rather new and simple technique can measure mass concentrations in vehicle exhausts in real-time. Furthermore, in combination with Rayleigh scattering can yield mean particle size, D (nm) and Number density, N (#/cc).

Slide 5: In LII, soot particles are heated up to their sublimation temperature (~ 4000 K) and the ensuing thermal radiation when collected in a certain manner provides a signal directly proportional to the local mass concentration.

Slide 6: 2-D images of the soot fields measured in a laminar diffusion flame are shown. These images represent the capabilities of the LII + Rayleigh Scattering technique.

Slide 7: At the initial stages of the program, computer modeling was used to investigate the effects of various parameters on LII signal. Such a study showed that the LII signal could vary with the engine exhaust temperature (SAE 2001-01-0217). In a typical diesel, the exhaust temperatures could vary between 200 – 500^{o}C. To reduce the effect of temperature variations, it was decided to dilute the engine exhaust before measurement.

Slide 8, 9, 10: Initially experiments were performed in the exhaust of a sooting laminar diffusion flame. Varying the airflow rate in the burner varied the concentrations. Validation experiments were performed using a TEOM instrument. The signals measured are shown in slide 10. In such a setup, by performing a parametric study, it was determined that the required laser fluences are approx. 1.6 times those previously reported through inflame studies. The following measurements showed LII to be a very promising technique.

Slide 11: Subsequently, it was decided to reduce this technique into an instrument. Our initial sketches are shown in the left figure. However, to confirm to our objectives of (1) Low-cost (2) Portable (3) Independent of engine size (4) real-time and (5) modular in design, the final instrument resembled a 19 inch rack mount version as shown in the right figure. We will refer to this instrument as TG-1 henceforth.

Slide 12: The prototype TG-1 was used to measure in the exhaust of a Mercedes Benz 1.7 L engine coupled to a low-inertia dynamometer. An SMPS provided the validation measurements. The agreement is shown in the graph on the right.

Slide 13: To investigate the real-time measurement capabilities, the instrument was tested by switching the engine between three steady-state modes in a step like manner. While TG-1 proved far superior the TEOM-1100 showed negative values in certain regions. Rupprecht and Patashnick Co. which manufactures the TEOM when contacted mentioned that most of the problems were addressed in their current version of the instrument, i.e., TEOM 1105.

Slide 14: Subsequently, a TEOM 1105 was procured and validation tests were performed. As the manufacturer had mentioned many of the problems were corrected in TEOM 1105.

However, as shown in slide 9, one ought to realize that a TEOM measures the mass concentration by performing a derivative. A parametric study performed by varying the two time constants T_{MC} and T_{TM} in the TEOM software showed that both the time constants to be set to a minimum of 5 secs in order to obtain reasonable measurements. As a result, the minimum window for moving average is 5 secs for a TEOM 1105. TG-1 on the other hand provided comparable measurements with as little as 0.3 sec moving average.

Slide 15: The comparative performances of TG-1 and TEOM 1105 while step changing the engine through three steady-state modes is shown.

Slide 16: Similar comparative performances while operating the engine through a portion of the urban driving cycle is shown.

Slide 17, 18, 19: Self-explanatory.

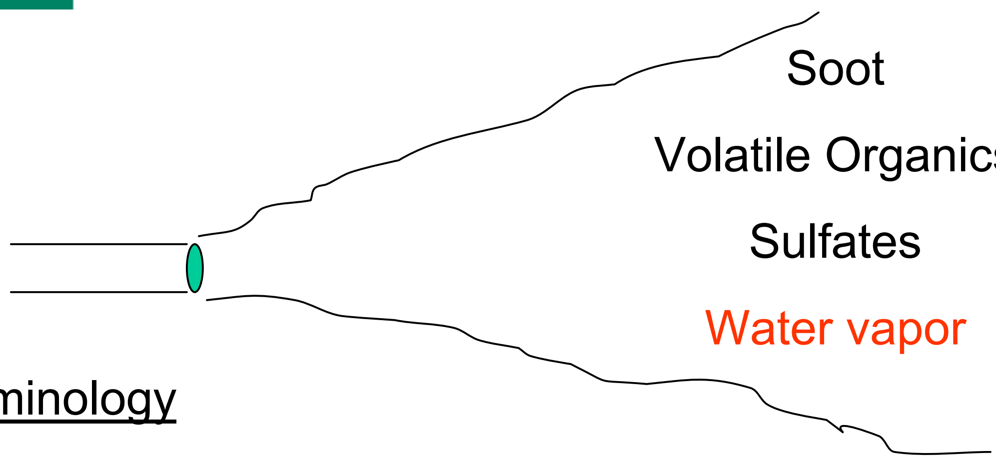
- *Patents pending.*
- *For industrial partnership contact* ragland@anl.gov *Tel: (630) 252 3076*

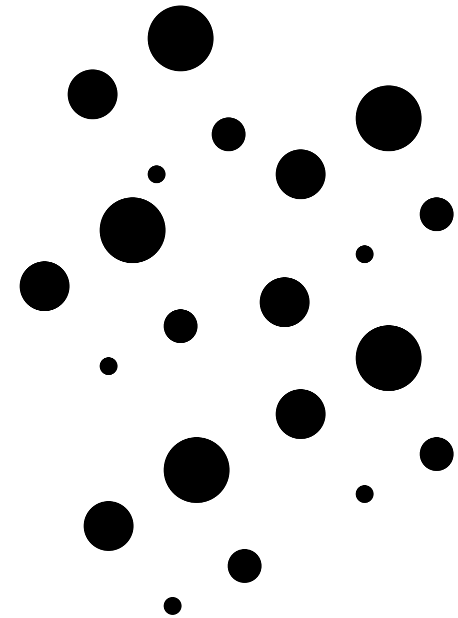
TG-1: Instrument to Measure Diesel Exhaust Particulate Emissions in Real-time

S. Gupta
Engine and Emissions Research
Argonne National Laboratory

ETH Conference
Zurich, 08/19/02

Diesel Exhaust Particulate Aerosol





Terminology

Mass Concentration	MC	(gms/cc)
Number Density	N	(Number of Particles/cc)
Mean Particle Diameter	D	(nm)
Soluble Organic Fraction	SOF	(gms/cc)

Real-time Quantitative Measurements Difficult With Current Instrumentation

Smoke Meters (Bosch, Hartridge)	- quantitative measurements difficult
Filter Paper Collection (Sierra, Horiba, etc.)	- steady state - overall measurement time 36 hrs typical
TEOM (Rupprecht & Patashnick Co, NY)	- measurement every ~ 5secs - could result in negative values
ELPI (TSI, Inc.)	- transients possible - extremely low size resolution
SMPS (TSI, Inc.)	- scan times typically 60 sec

Laser Induced Incandescence (LII)

- Primarily measures volume fraction, f_v

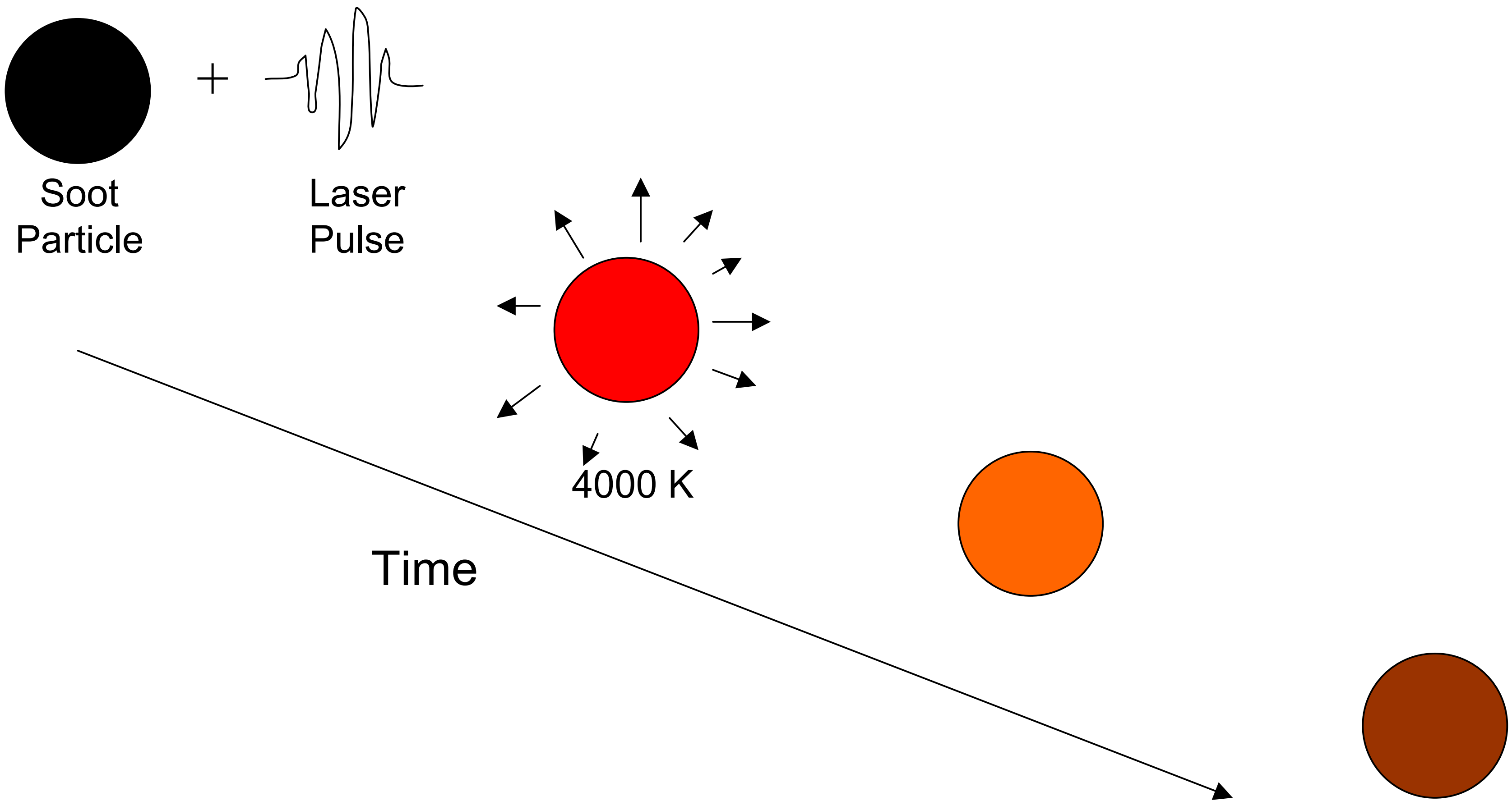
$$f_v \times \rho = MC \text{ (grams/cc)}$$

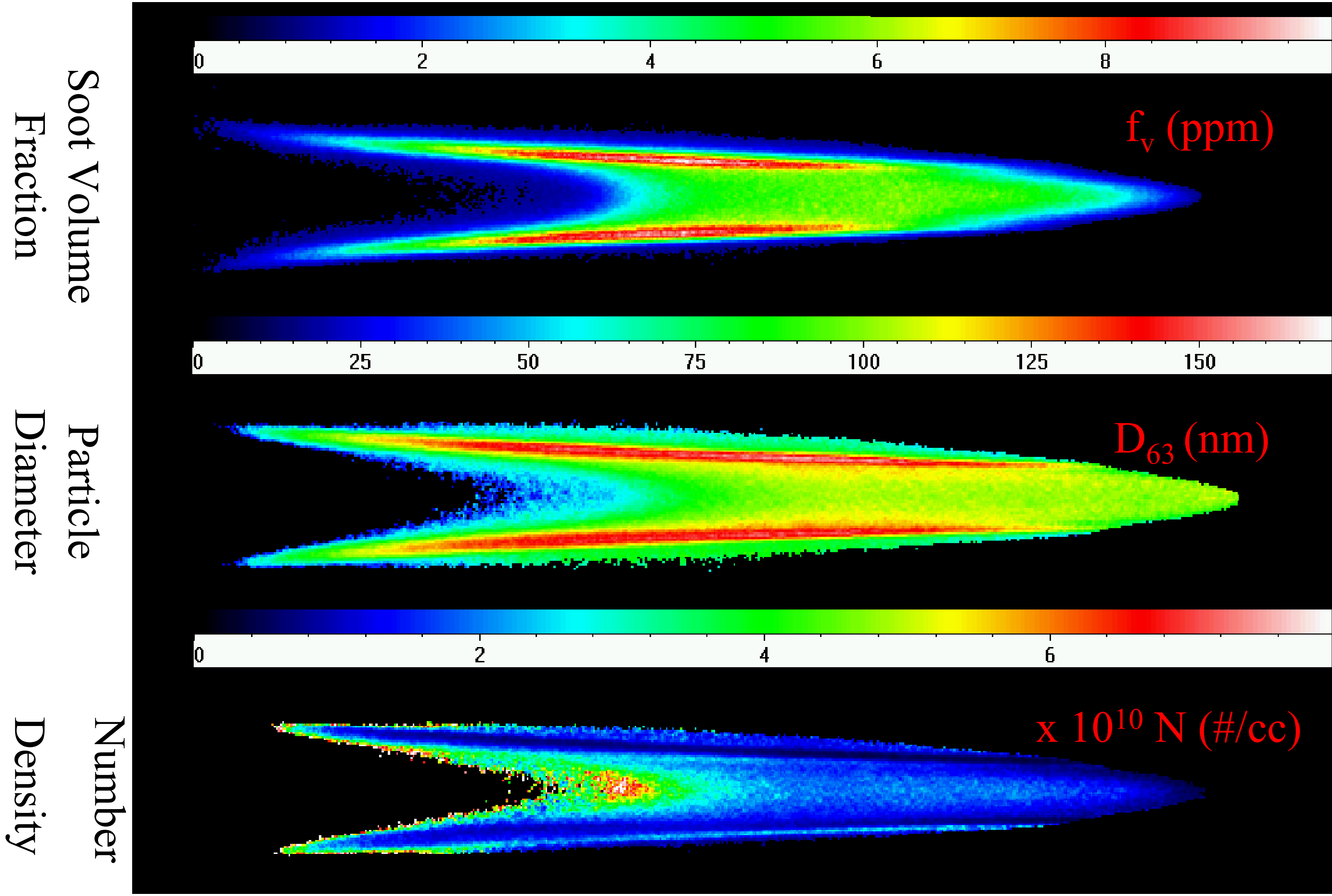
- Can measure in real time; 10 Hz typical
- In combination with Rayleigh scattering yields

Mean particle size (nm) $$D = K_1 \cdot \left(\frac{Q_{vv}}{MC} \right)^{1/3}$$

Number density (#/cc) $$N = K_2 \cdot \frac{MC}{D}$$

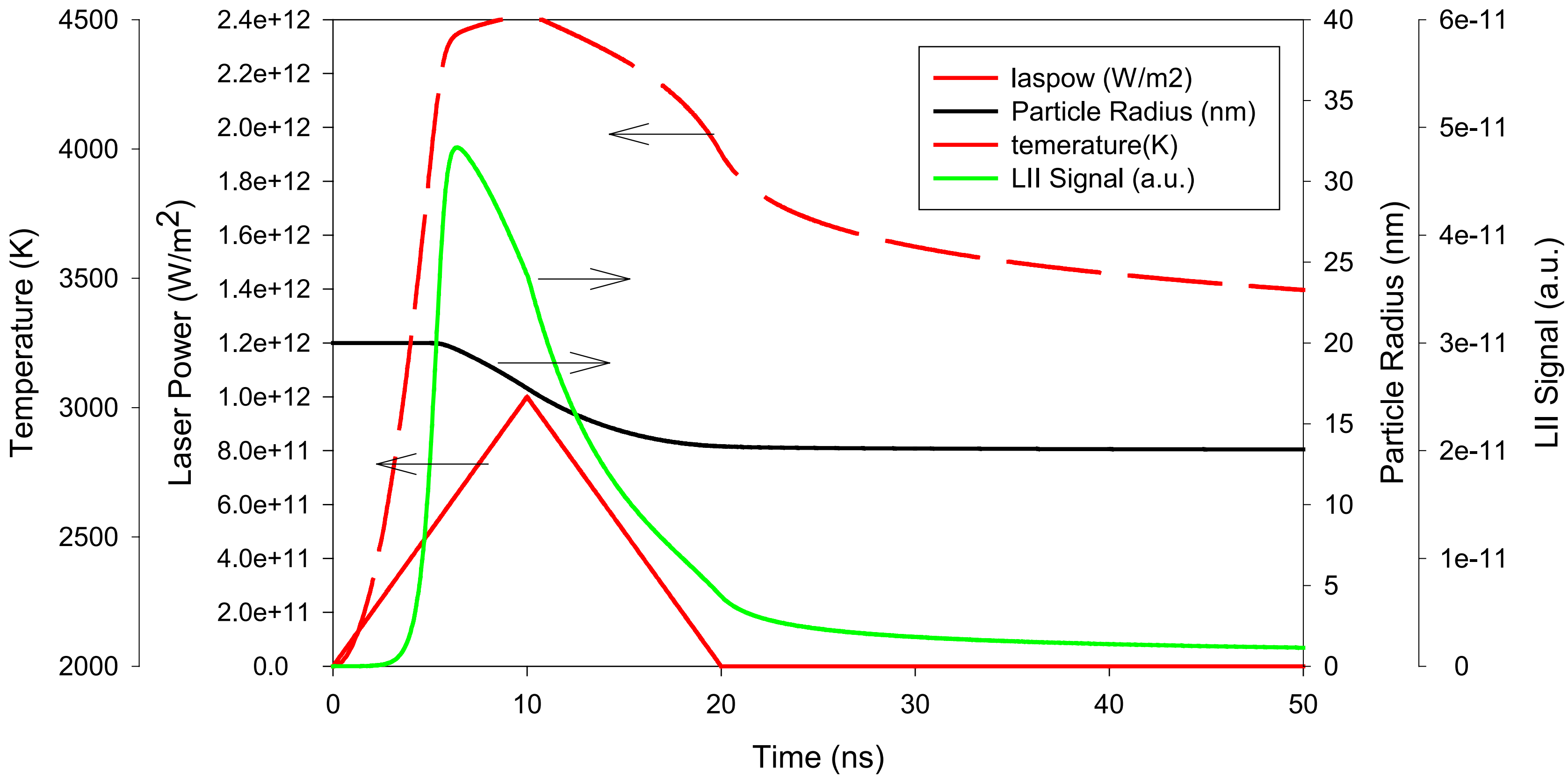
LII Phenomenon





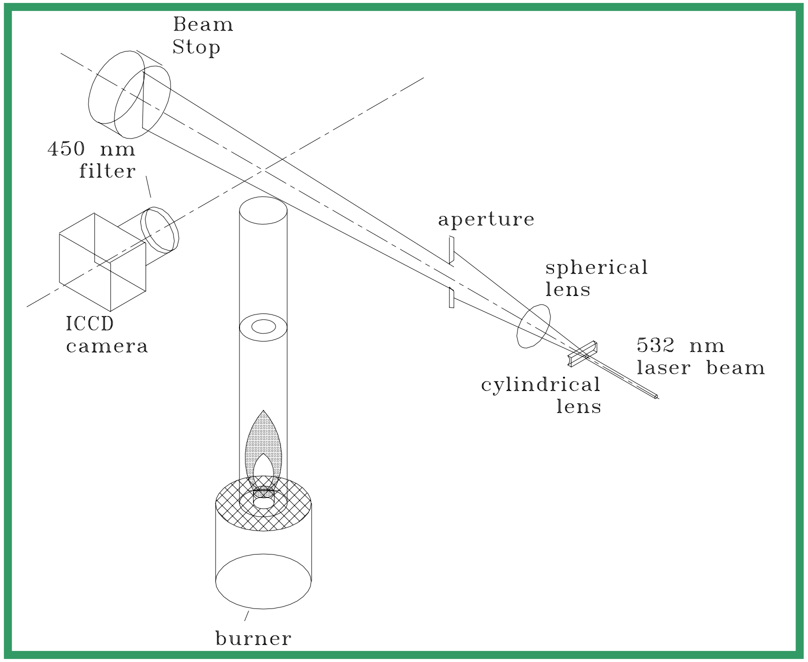
Soot Volume Fraction
0 2 4 6 8
f_v (ppm)
Particle Diameter
0 25 50 75 100 125 150
D_{63} (nm)
Number Density
0 2 4 6
x 10^{10} N (#/cc)

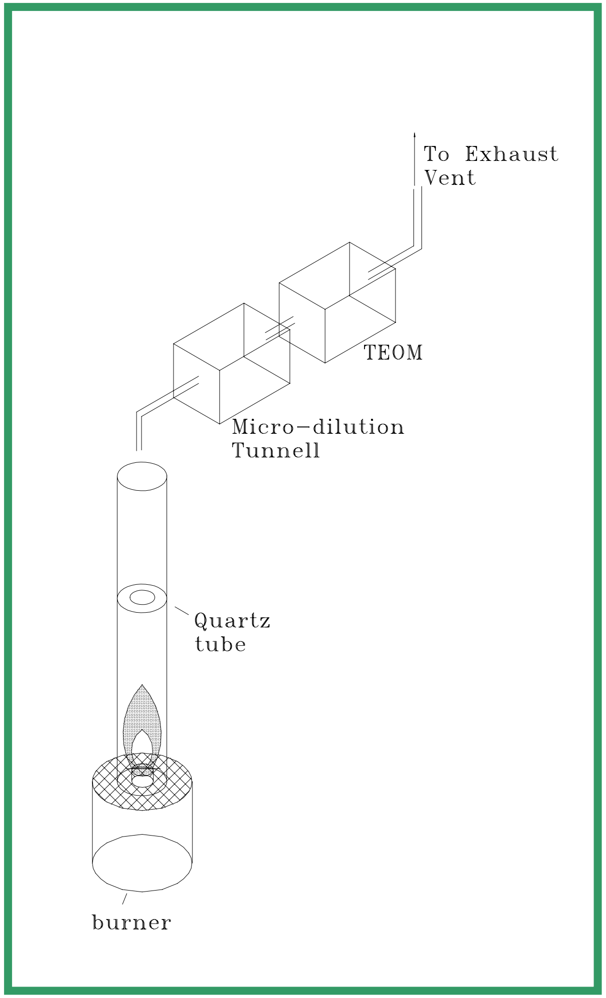
LII Computer Modeling was Used to Gain Insight Into the LII Phenomenon



LII signal strongly varies with initial particle temperature; for typical diesel exhausts (200 - 500^{o}C) dilution is necessary

Bench scale LII Experimental Setup





Tapered Element Oscillating Microbalance (TEOM)

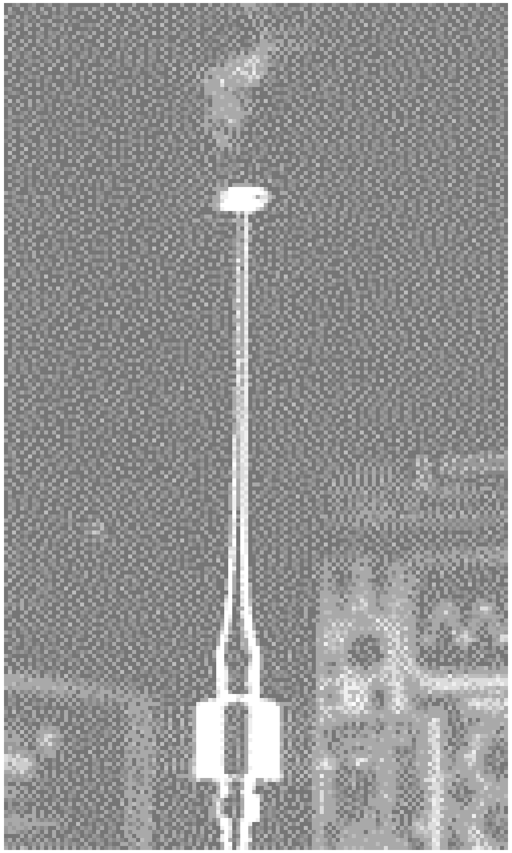
<u>Tapered Element Oscillating Microbalance</u>

Measures Mass Concentration, M (g/cc) in Diesel Exhausts

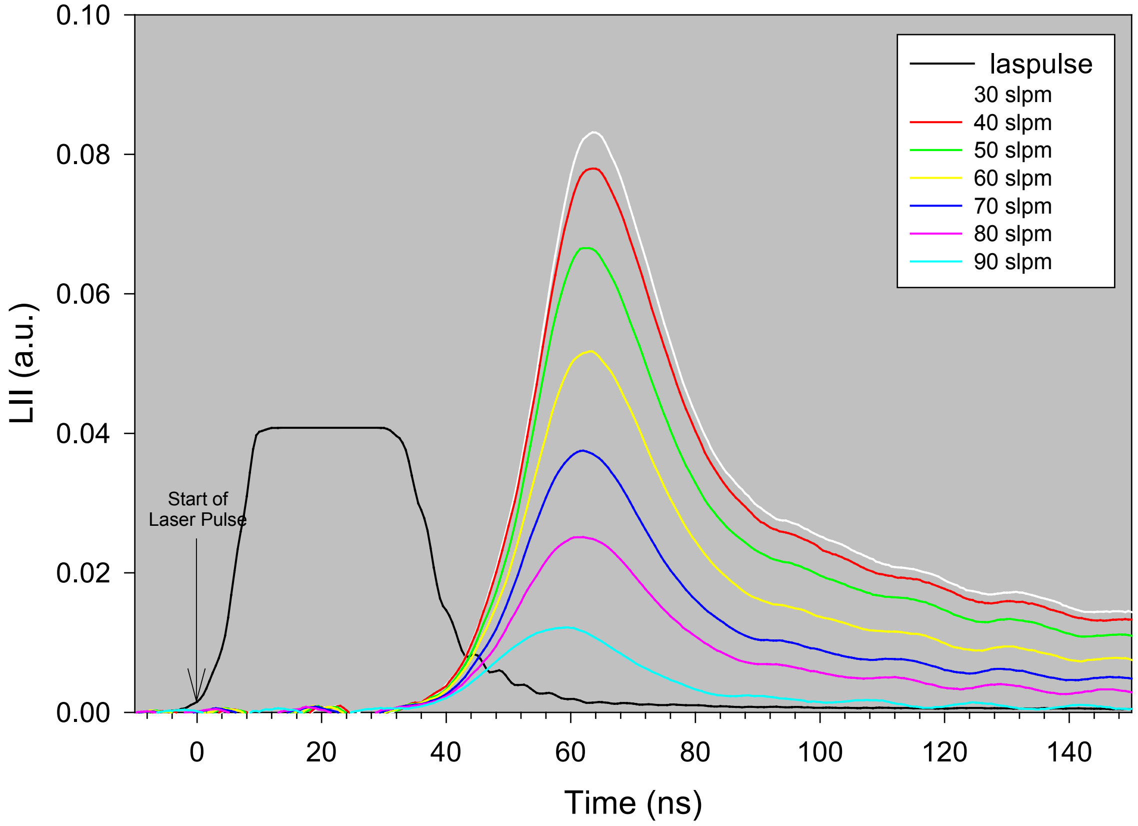
$$M = \frac{k_o}{f^2}$$

$$MC = \frac{1}{V}\frac{dM}{dt} = \frac{1}{V}\frac{-2k_o}{f^3}\left(\frac{df}{dt}\right)$$

$\therefore$ f as well as $\frac{df}{dt}$ need to be measured accurately.

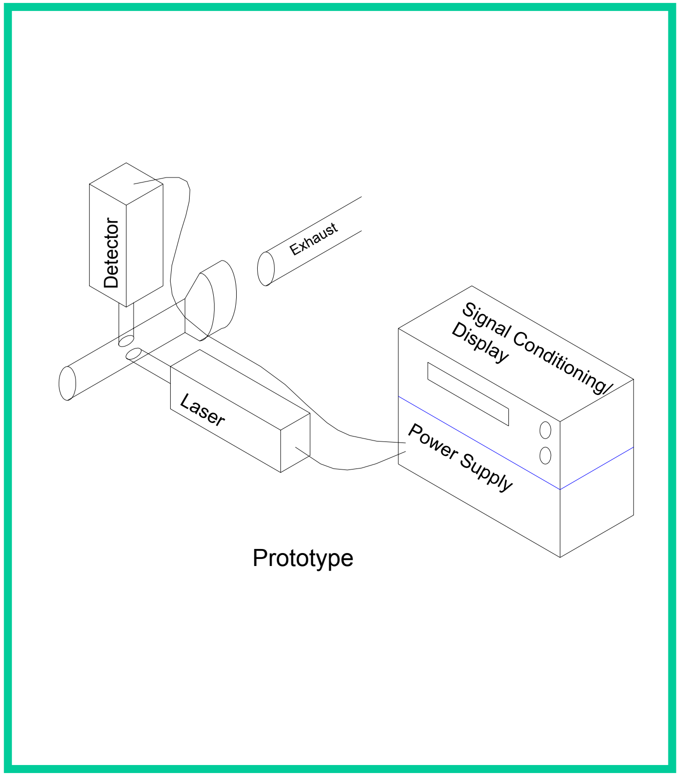


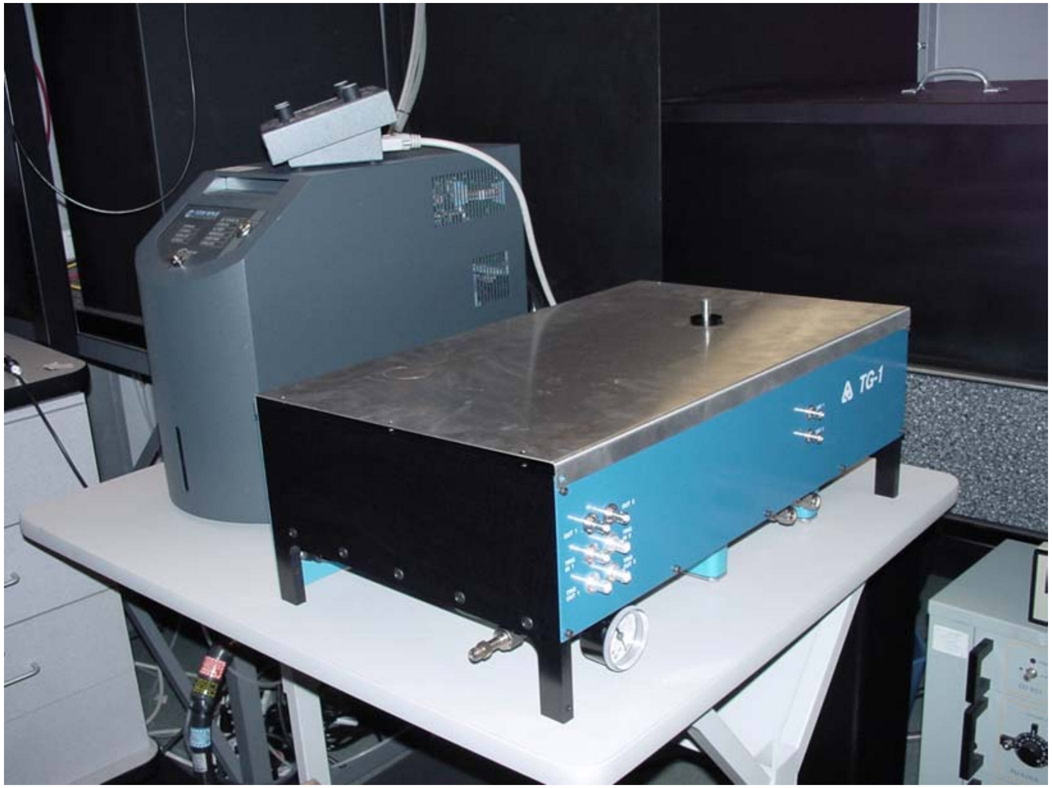
Critical Operational Parameters were Determined Through Experiments



Parametric study shows optimal laser fluence ~ 1.6 times that previously recommended through in-flame studies

A Portable Prototype Instrument has Been Developed

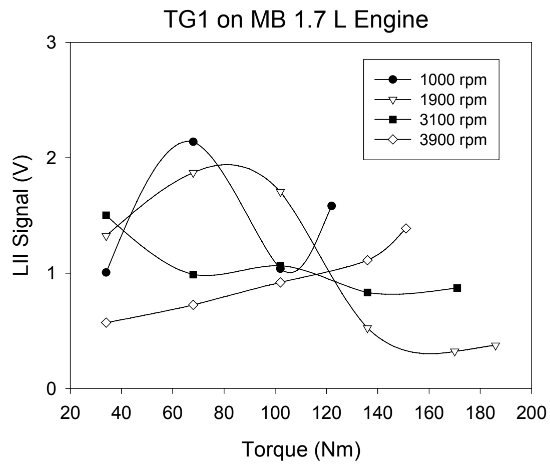


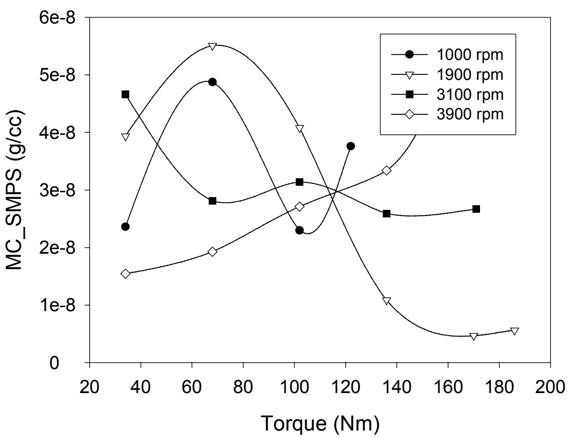


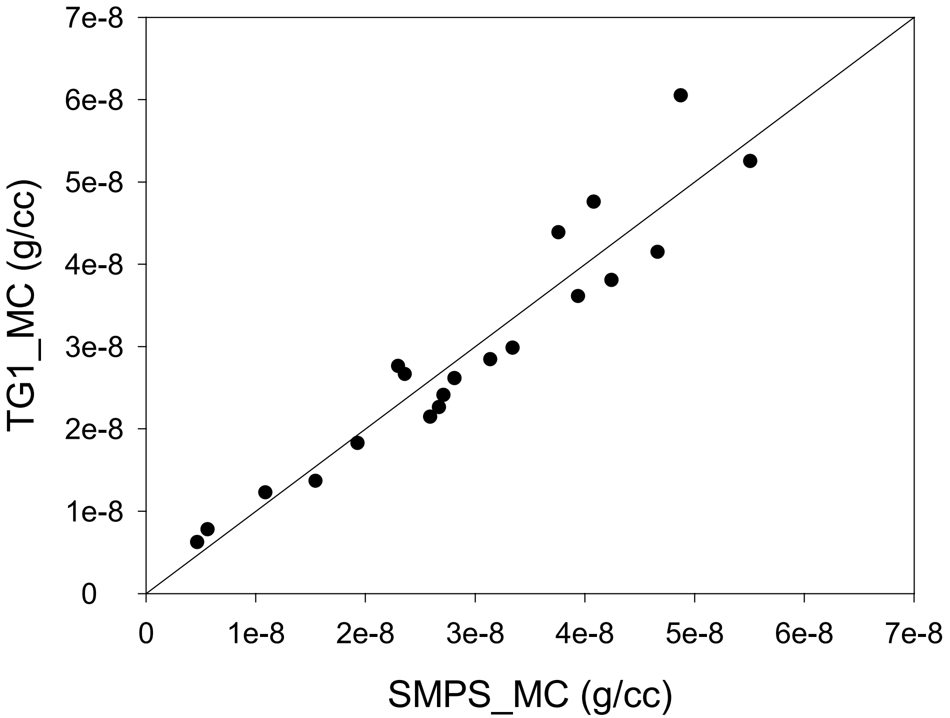
Low-cost **Portable**

Cross-platform **Real-time** **Modular design**

TG-1 Shows Excellent Performance Over Typical Diesel Engine Operation

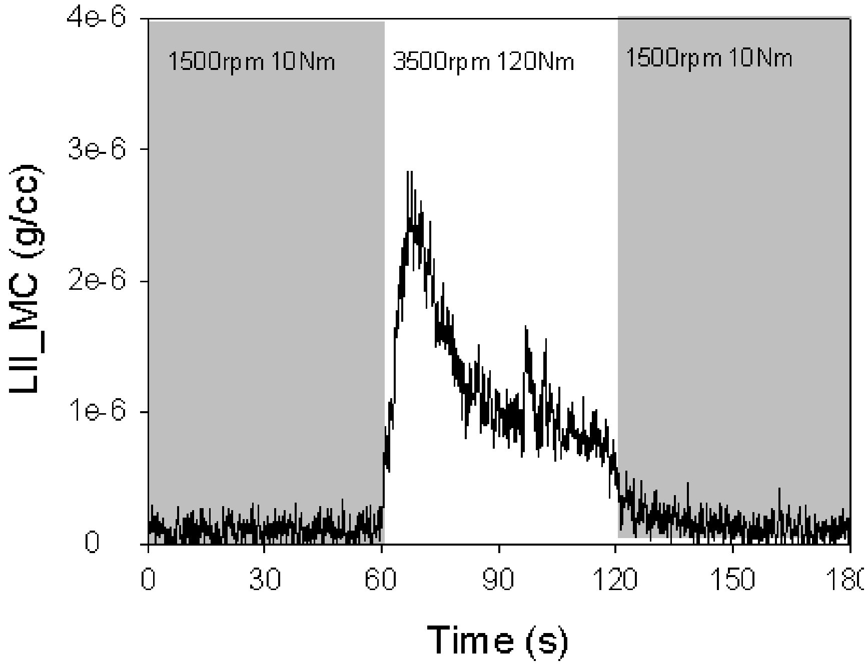




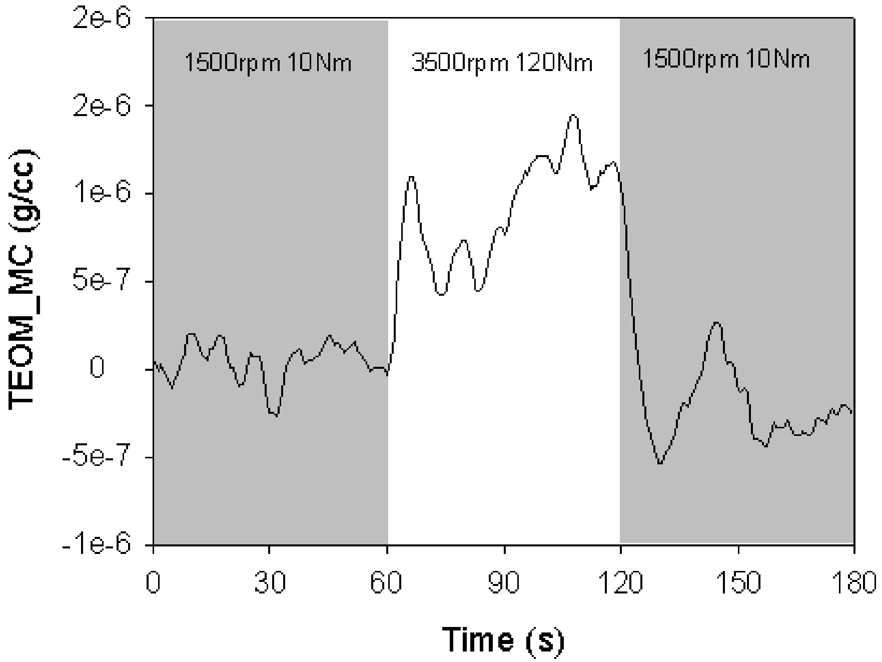


Transient response of TG1 Proved Superior Over That of TEOM 1100

MB 1.7 L engine coupled to a low-inertia dynamometer

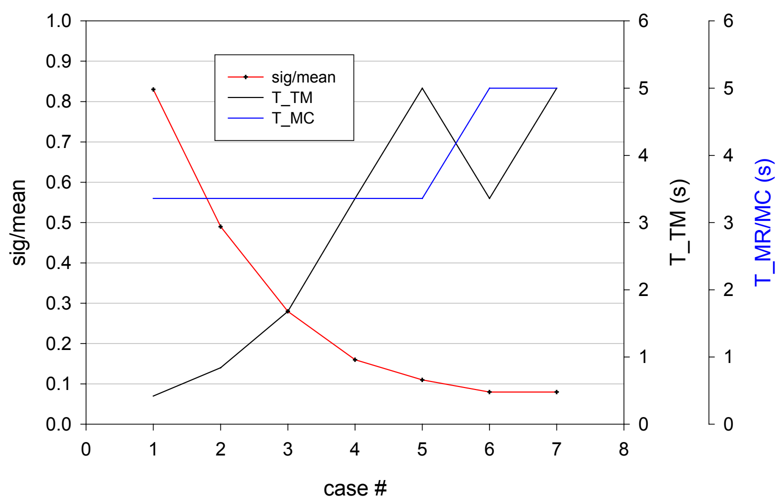


TG1

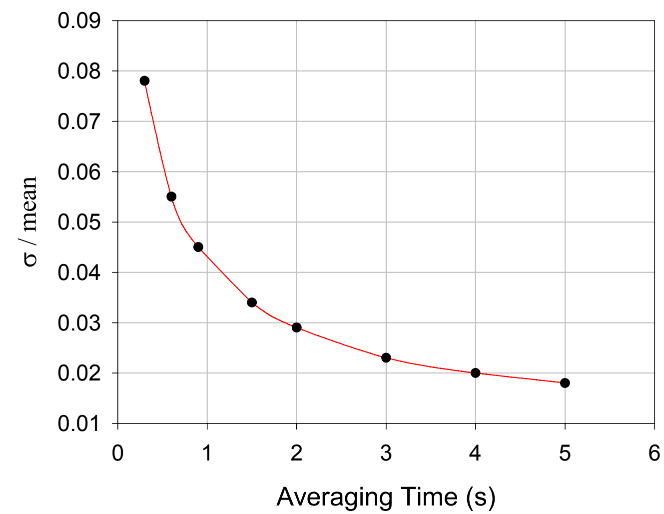


TEOM 1100

TG-1 has Faster Time Response Than a TEOM 1105



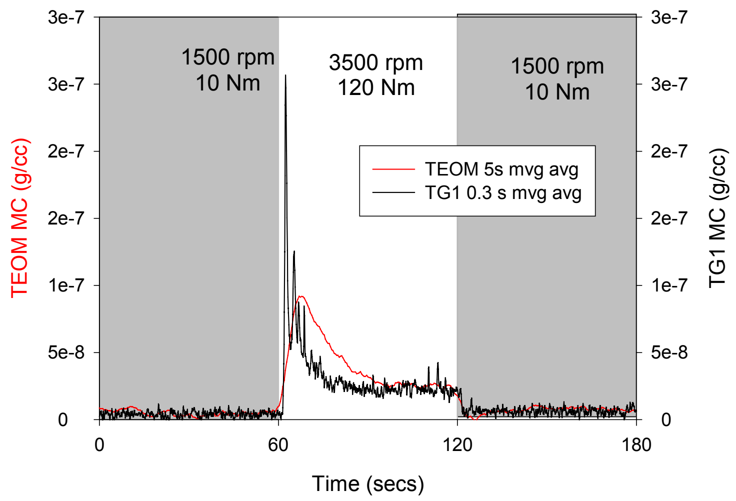
TEOM-1105

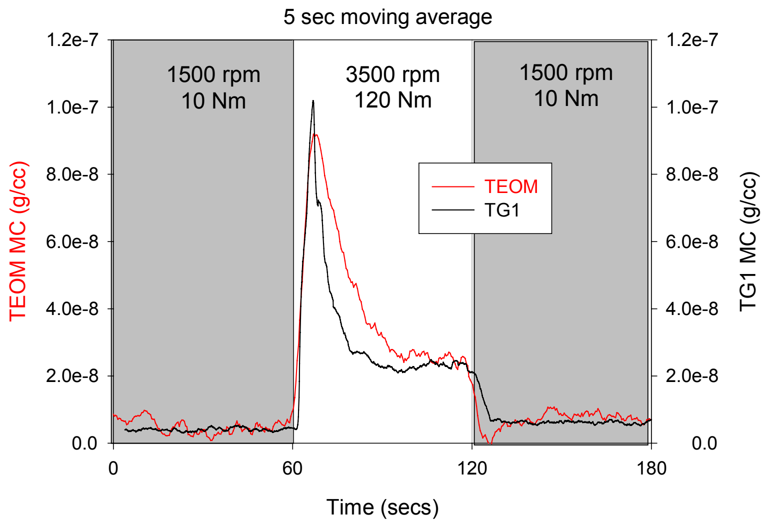


TG-1

TG-1 has Faster Time Response Than a TEOM 1105

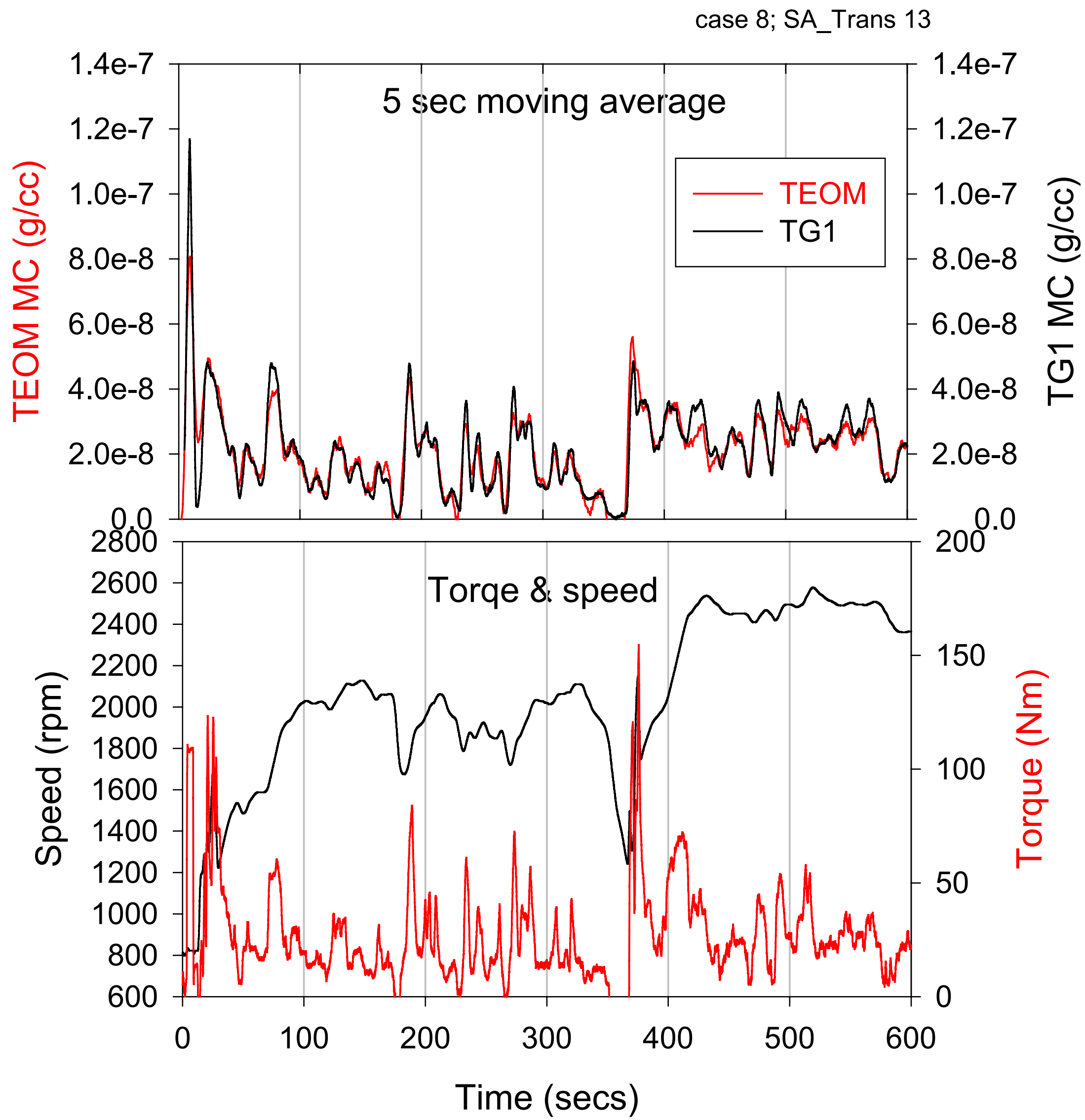
5 second moving average





Transient measurements performed on a Mercedes Benz 1.7 L engine coupled to a low-inertia dynamometer

TG-1 Performance Over the Urban Driving Cycle



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Specifications for Prototype TG1

Size: (24” x 15” x 8.5”) for TG1 + (19” x 8.6” x 15”) for laser power supply

Weight: Approx. 40 lbs. for TG1 + 55 lbs for laser power supply.

Accuracy/ variability: ± 12% Full scale as compared to SMPS measurements.

Repeatability: (not yet determined)

Cost: To be determined

Compatibility: Independent of engine size

Known Problems...

- Diluter needs constant cleaning
- Sample cell windows need cleaning every 1-3 days of operation
- Needs zero and span calibration almost everyday

Future Plans

- Install capabilities to measure N and D in real-time
- Decrease the size and weight; 19 in. rack mount version
- Market introduction through Sierra Instruments Inc., CA.

Acknowledgements

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