On-Board Engine Exhaust Particulate Matter Sensor for HCCI and Conventional Diesel Engines

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Project Manager: Ralph Nine

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Project ID #ace_44_hall

Overview

Timeline

- Project start date: 10/1/2006
- Project end date: 12/31/2009
- Percent complete: 80%

Budget

- Total project funding
  - DOE share: $412,203
  - Contractor share: $392,305
- Funding received in
- FY08 : $137,450
- FY09: $136,745

Barriers

- Barriers addressed
  - "Develop new sensitive real-time PM measurements diagnostics for developing engines with ultra low-PM emissions, especially for rapid transients, and for providing the engine-out emissions characterization needed for design optimization and life-cycle analysis of PM aftertreatment systems."

Partners

- Interactions/ collaborations:
- Emisense/Ceramatec Inc.
- Cummins Engine Co.

- Project lead: UT-Austin

Study Objective

- Complete the development of an inexpensive, sensitive, accurate, and durable on-board particulate matter (PM) sensor, bringing it to a point where it can be commercialized and marketed.

Year 3 Objectives

- Continue development of PM sensor to further improve durability, sensitivity, and signal-to-noise ratio.
- Demonstrate PM sensor durability and response through on-board diesel vehicle studies.
- Explore sensitivity limits of PM sensor for ultra-low PM exhaust concentration levels upstream and downstream of DPF in 2008 model year Cummins 6.7 liter engine.
- Investigate velocity dependence of PM sensor signal and compensation techniques.
- Continue collaboration with Emisense/Ceramatec, Inc. to further the commercialization of the sensor.

Milestones

Month/Year	Milestone or Go/No-Go Decision
June-08	Go/No-Go decision: Decision made to focus future development on foil-electrode type sensors instead of wire electrode sensors. Foil-type sensors found to have greater sensitivity, less vibration noise, better durability.
February 2009	Milestone: Demonstration completed of higher durability (> 10s of hrs) PM sensor applied to diesel vehicle with validation of sensor sensitivity via filter measurements of PM emission concentrations from the 1.9 liter Fiat/Opel engine in the Chevrolet Equinox and with the opacity meter.
March 2009	Milestone: Compete set up of 2008 model year Cummins 6.7 liter diesel engine to begin ultra -low PM concentration testing of sensor with and without a DPF

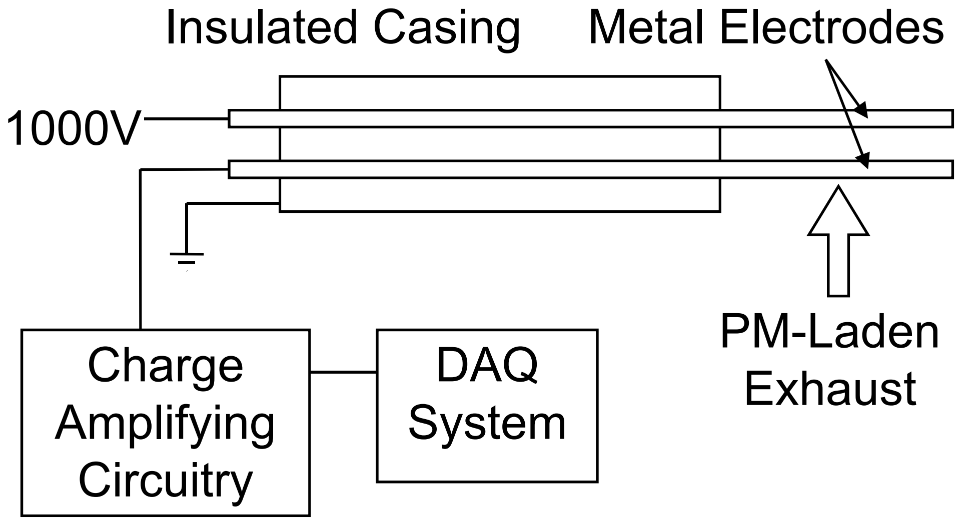
Approach

- New sensor designs that include active heating to prevent soot fouling and different electrode sizes and shapes for enhanced sensitivity will be created in cooperation with Emisense/Ceramatec, Inc.
- May include proprietary configurations and installation geometries to minimize velocity effects on signal.
- Continue on-board vehicle testing to demonstrate durability and sort out any installation issues and velocity effects.
- Start ultra-low PM concentration level sensor testing and development with Cummins 6.7 liter engine, with and without DPF.

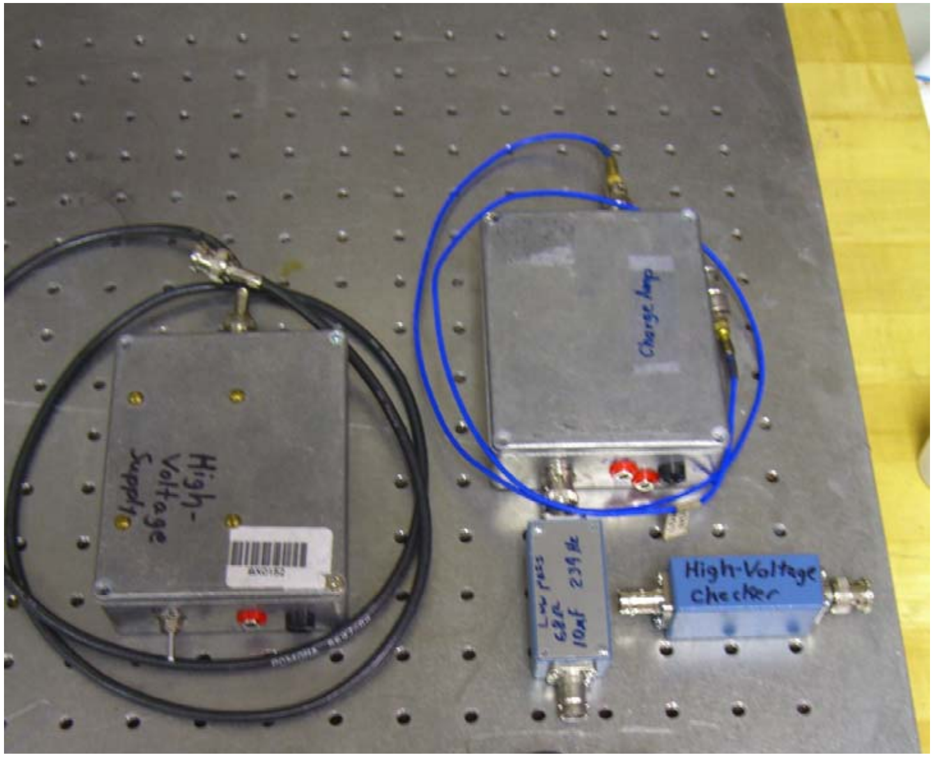
Background and Technical Accomplishments

Sensor Principle of Operation

- Soot particles in exhaust carrying a natural electric charge and are accelerated toward sensor electrode by a strong electric field and neutral particles are charged and detected.
- Rate of charge deposition on sensing electrode is proportional to PM content.
- Time resolution of 20 ms determined by charge amp electronics.



Sensor electronics



Test platform for on-board vehicle studies:

UT Austin Chevy Equinox
Engine: 1.9 liter Fiat/Opel Turbo Diesel
(with no exhaust after-treatment)

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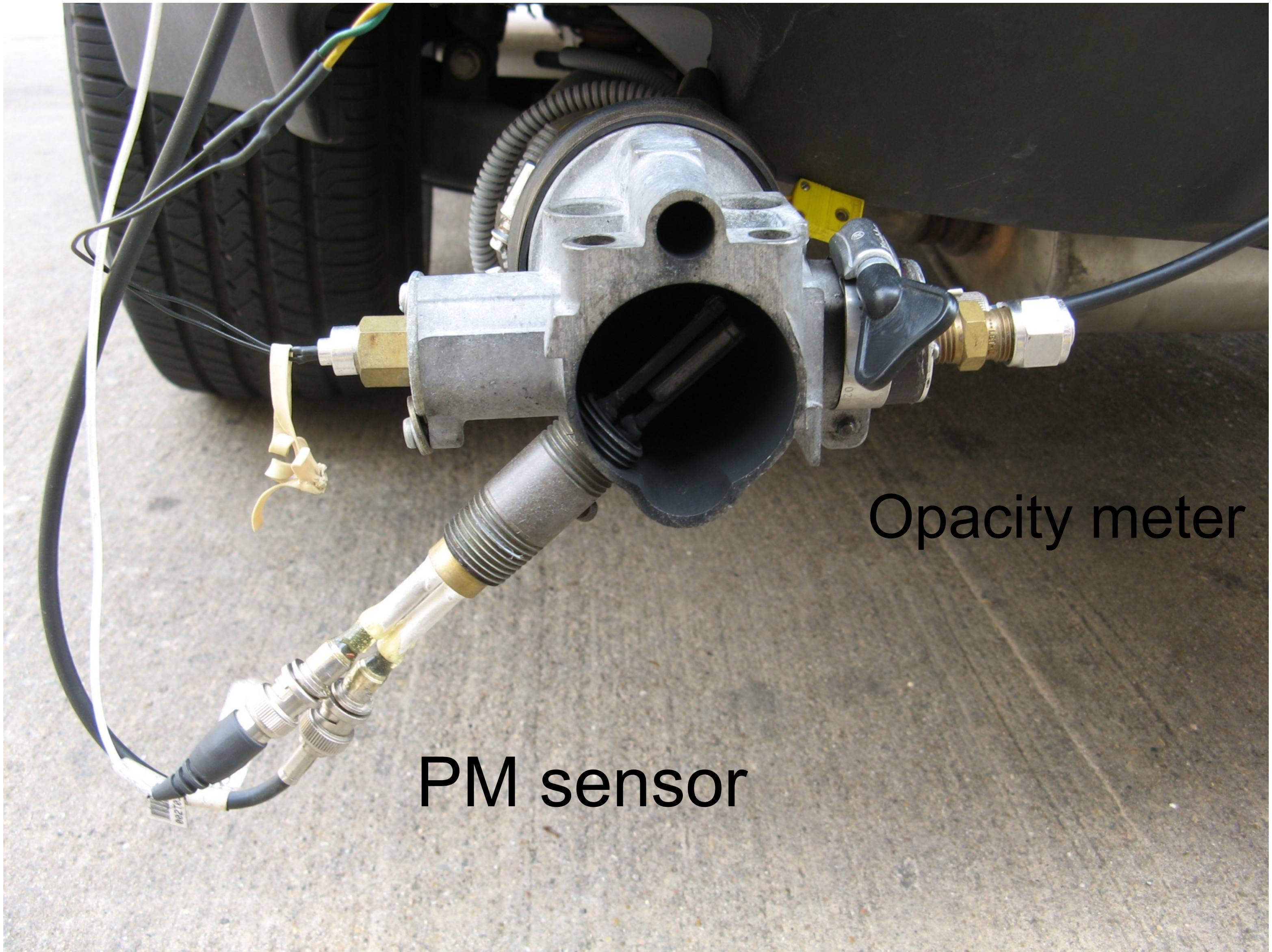
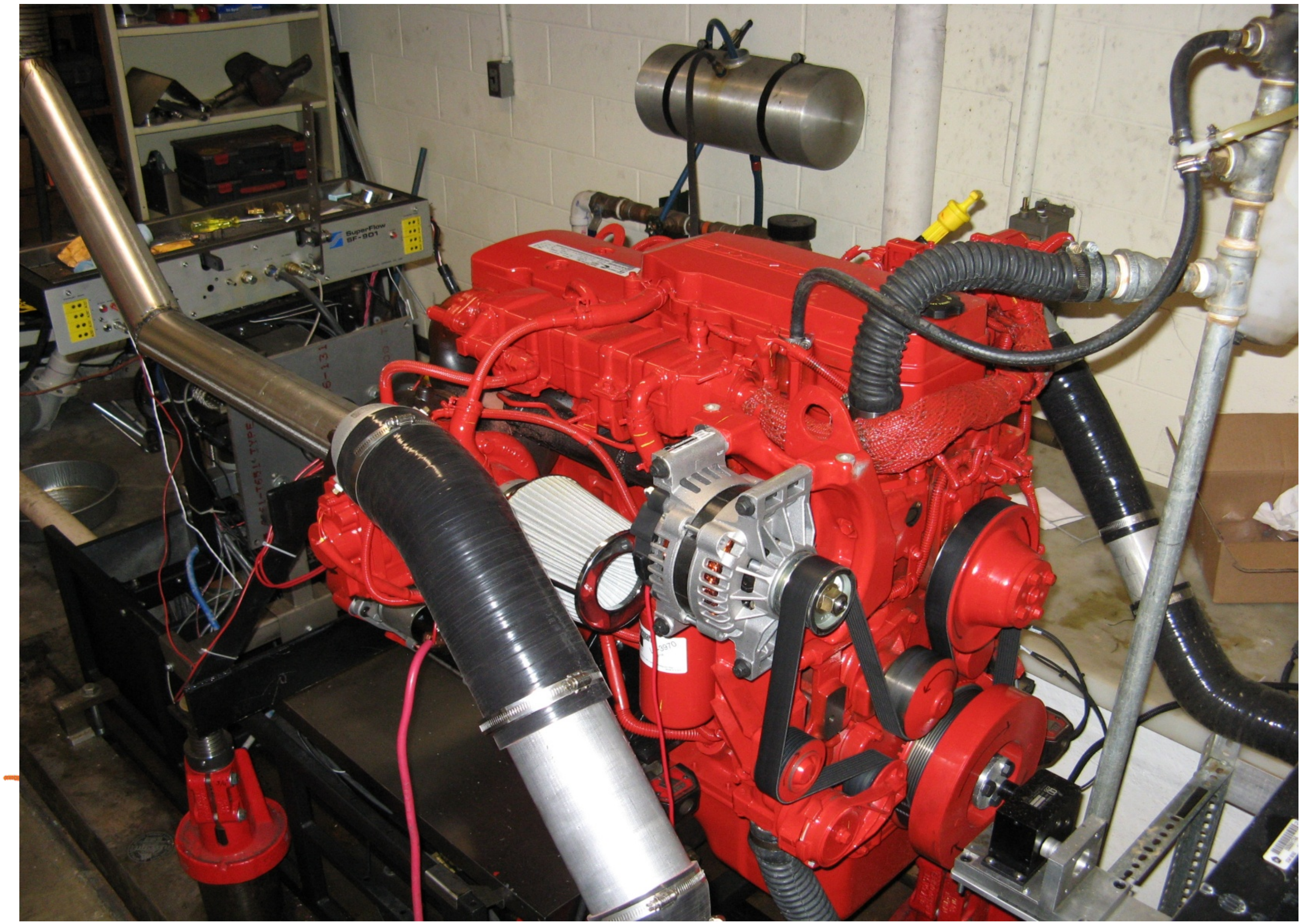
PM sensor and Opacity meter Installation

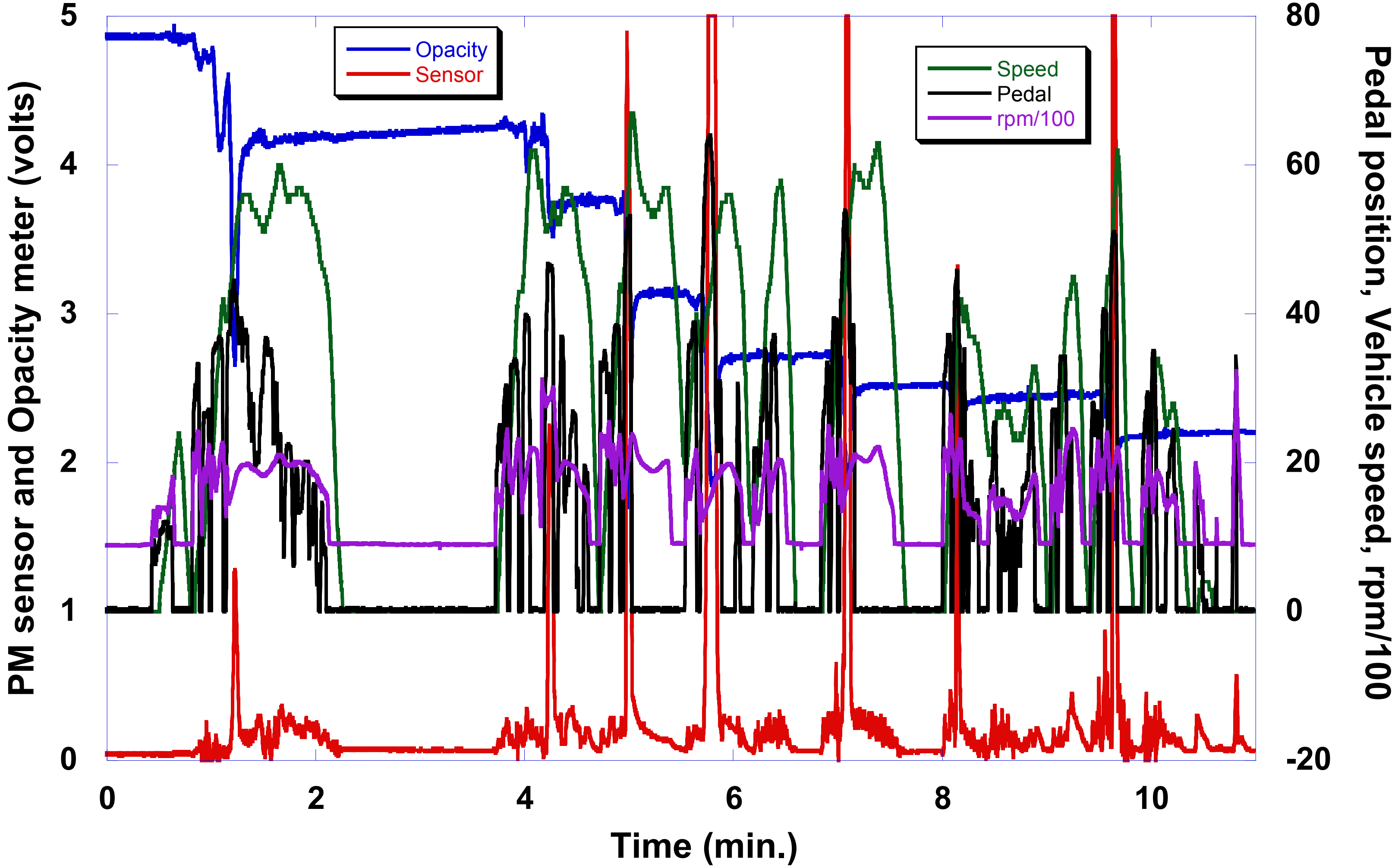


Test platform for ultra-low PM concentration level sensing with and without DPF: 2008 model year Cummins 6.7 liter engine



12 minute drive cycle in Equinox

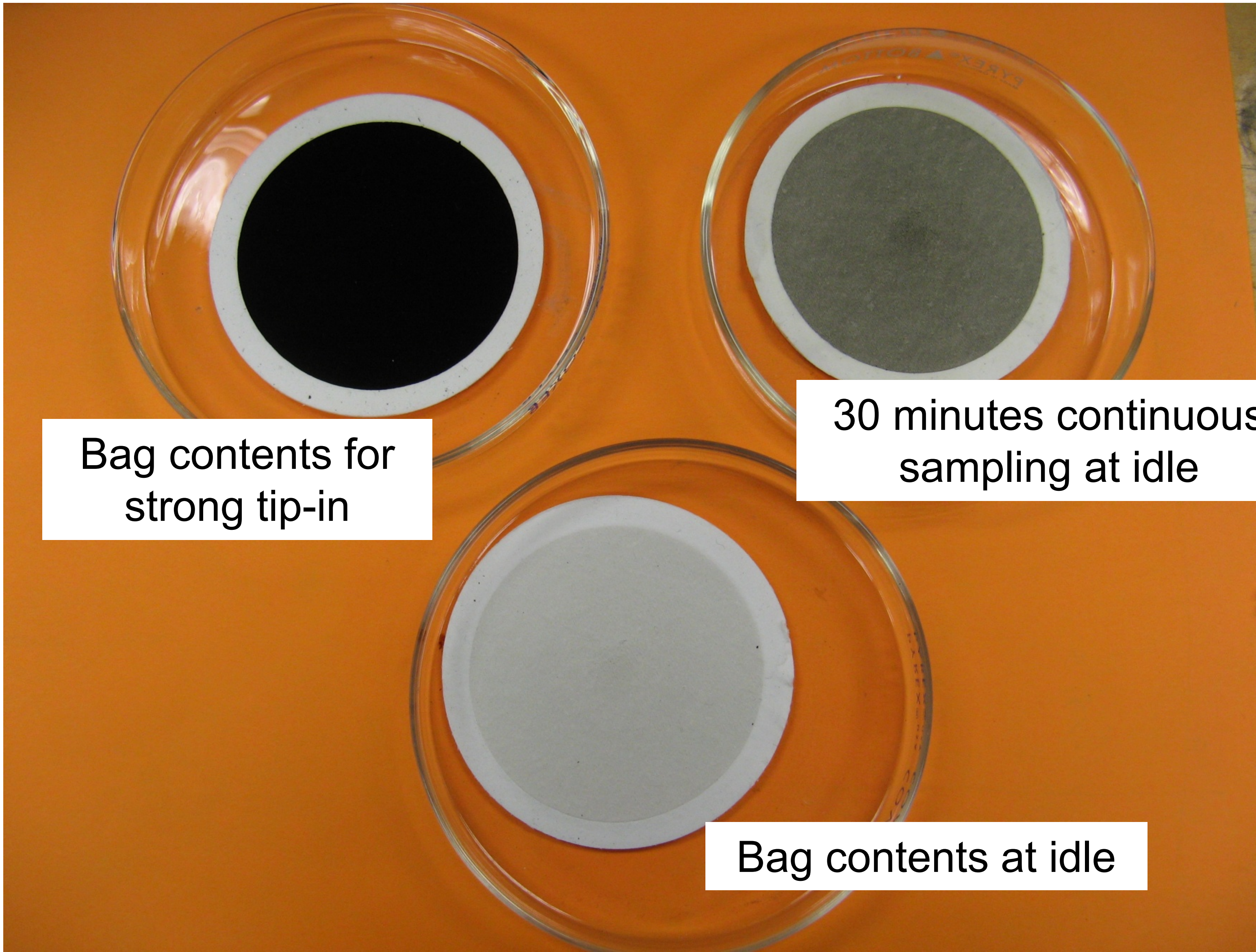
PM sensor output, Opacity meter output, vehicle speed (km/hr), Engine speed (rpm/100), Pedal Position (%)



Balances, sample bag, and filters used to calibrate PM sensor

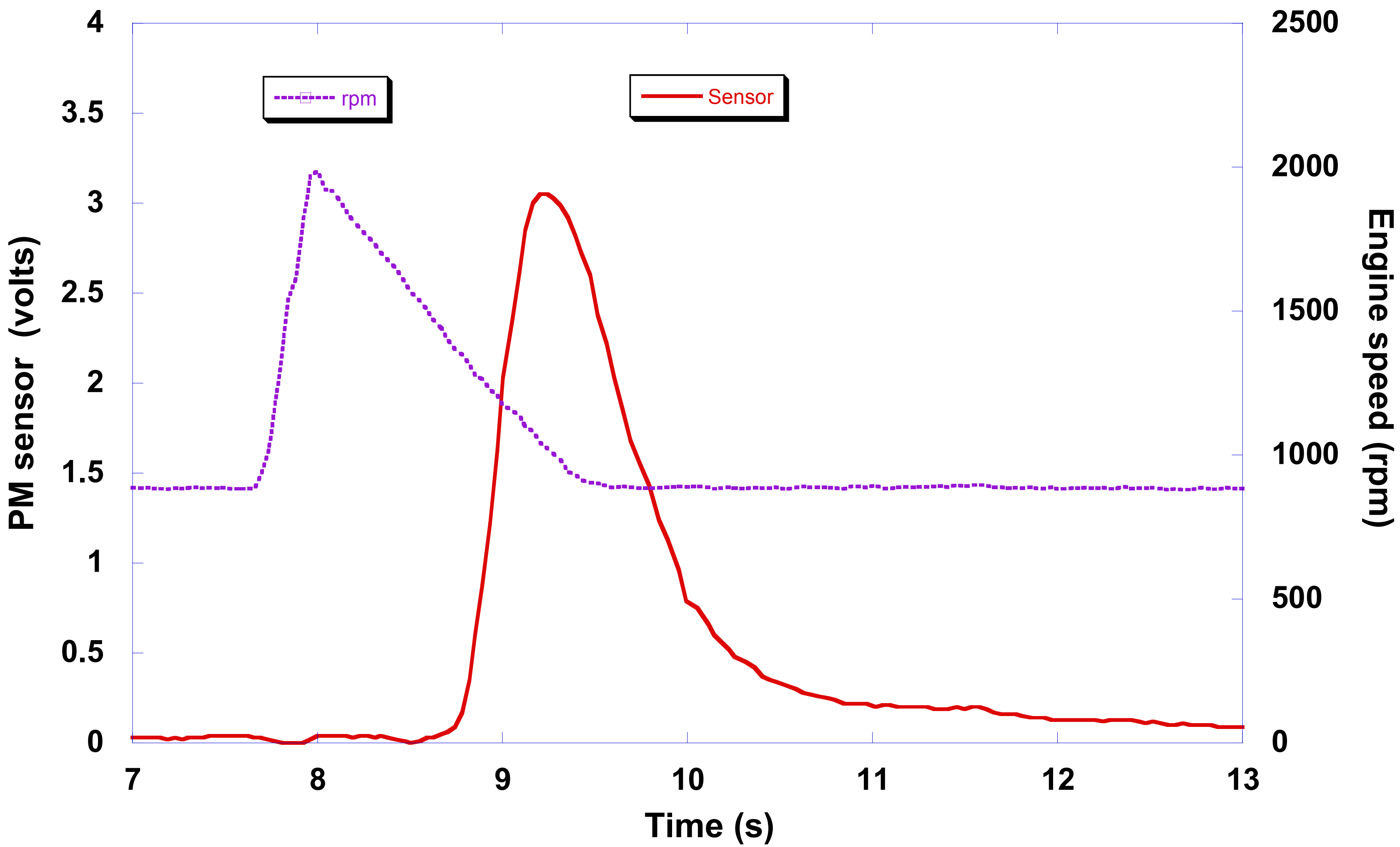
Filter measurements of exhaust PM mass

(Bag volume approximately 30 liters)



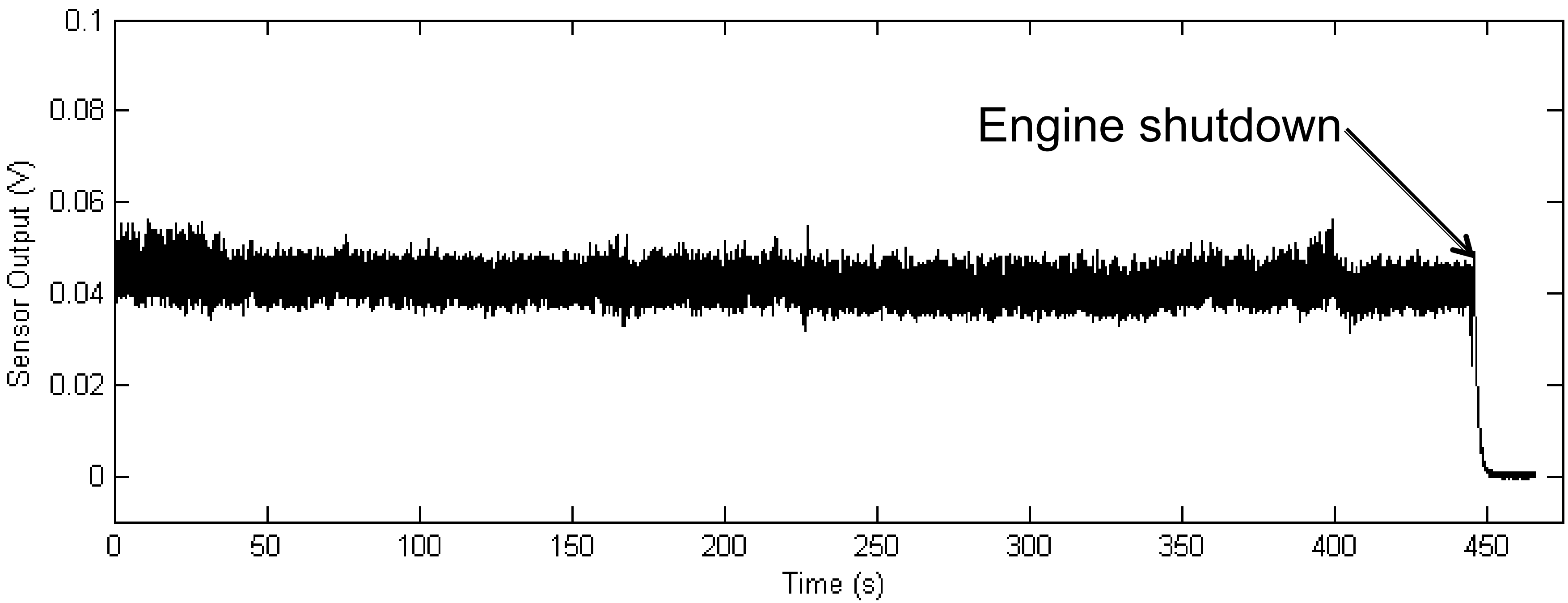
Sensor response and engine speed for an idle tip-in event

Gravimetric measured PM mass = 11.2 mg,
yielding sensor sensitivity of 204 mg/m^3 V

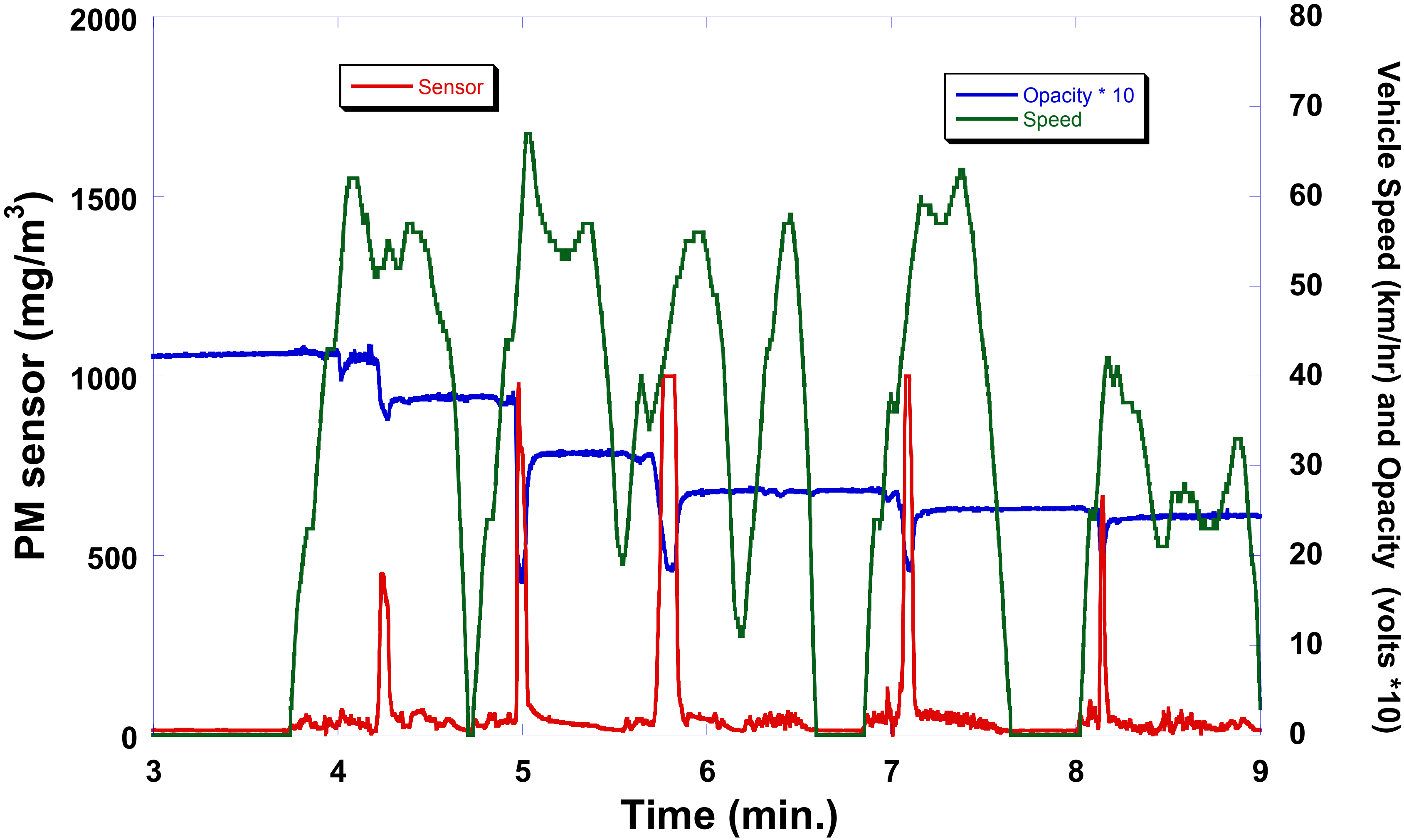


Exploration of sensor resolution and sensitivity limits
Single Cylinder Yanmar diesel engine

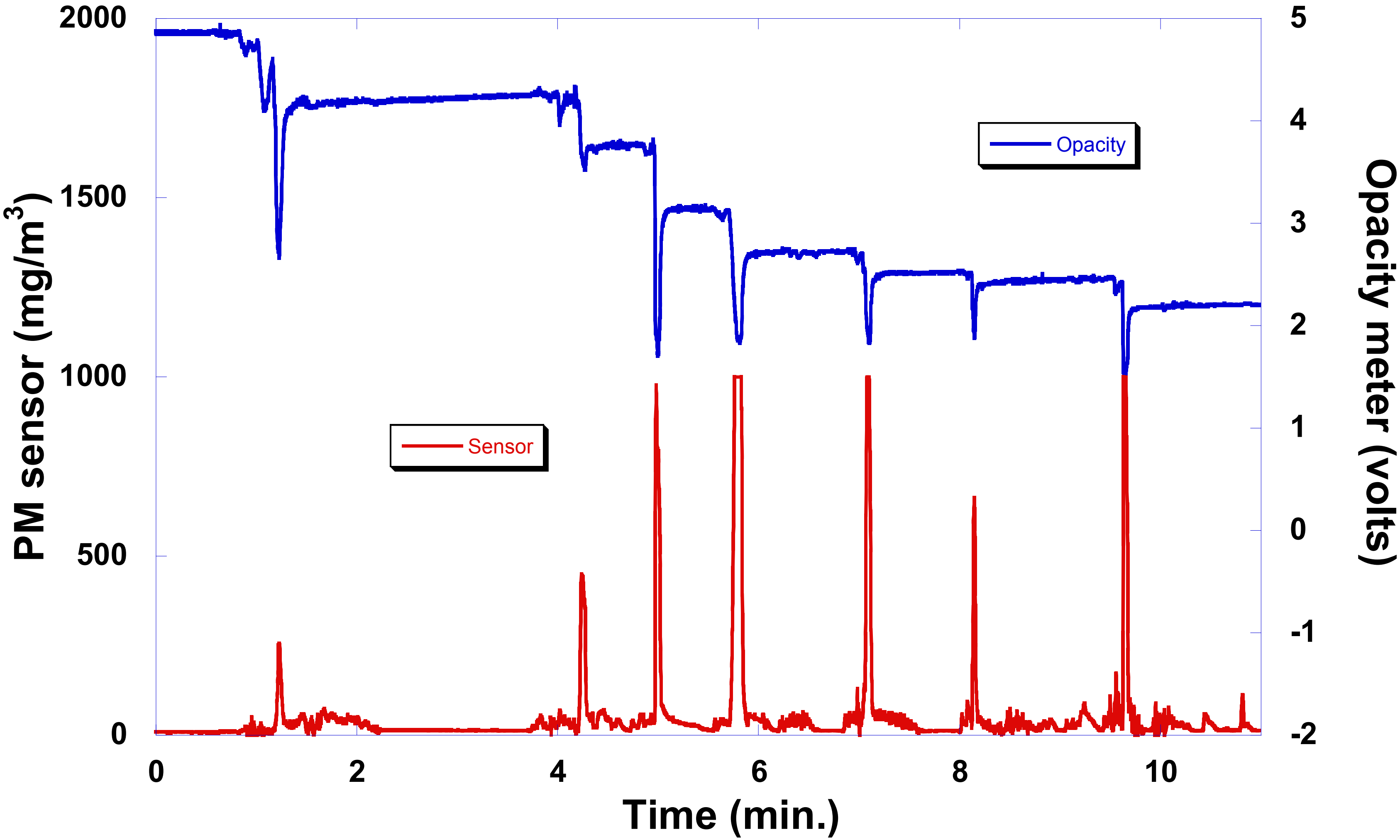
1500 rpm at a very low load of 1.5 Nm torque
Simultaneous filter measurement gave 17 mg/m^3 dry PM mass, yielding sensor sensitivity of 350 mg/m^3 V



PM sensor, opacity and vehicle speed (km/hr) during drive cycle
(No strong correlation of high emissions events with speed)

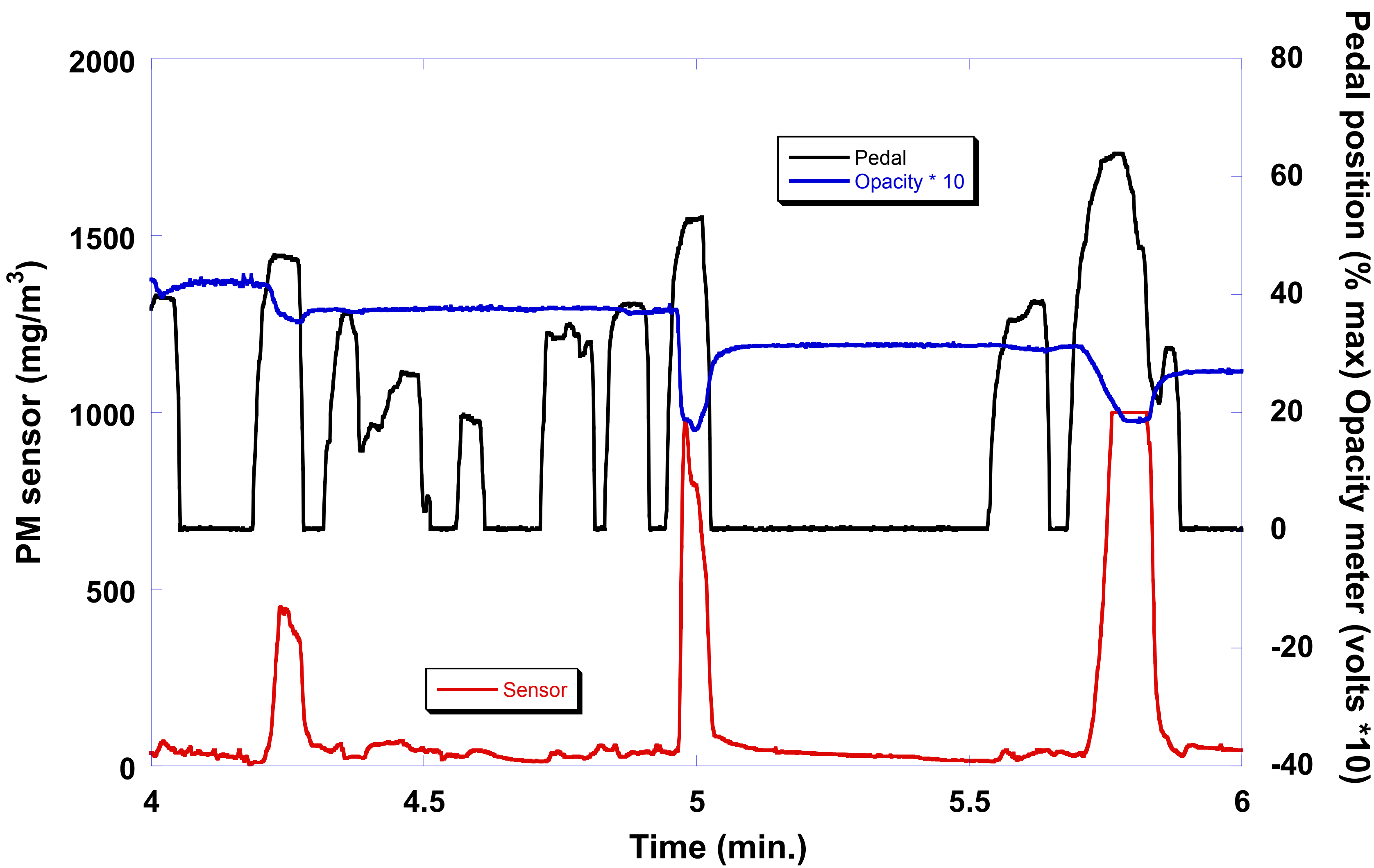


Calibrated PM sensor output (sensitivity = 200 mg/m^3 V) compared with opacity meter output for 12 minute drive (High emission events correlate well)



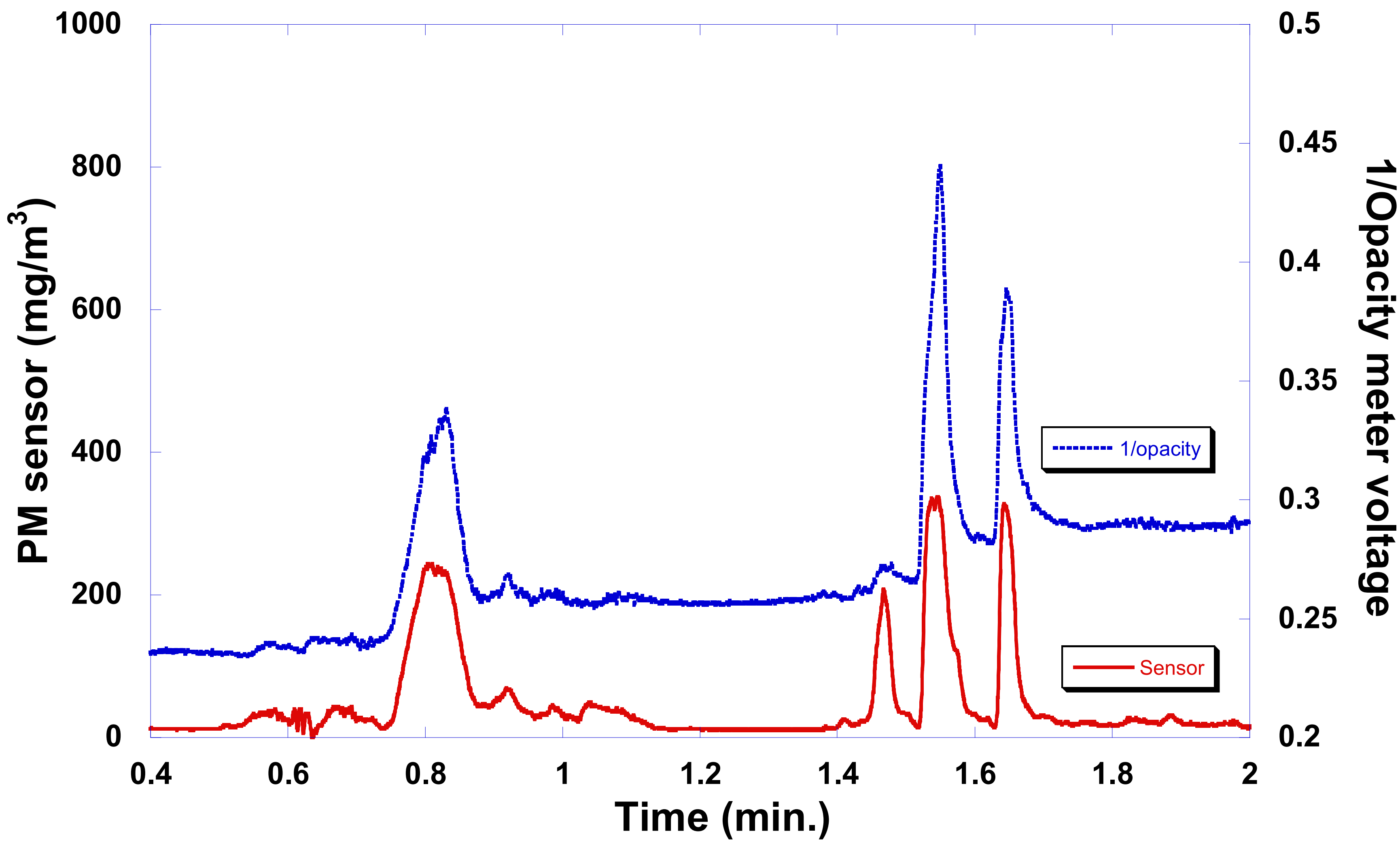
PM sensor output, opacity and pedal position during drive cycle

(High emission events occur for pedal positions >40% of max.)



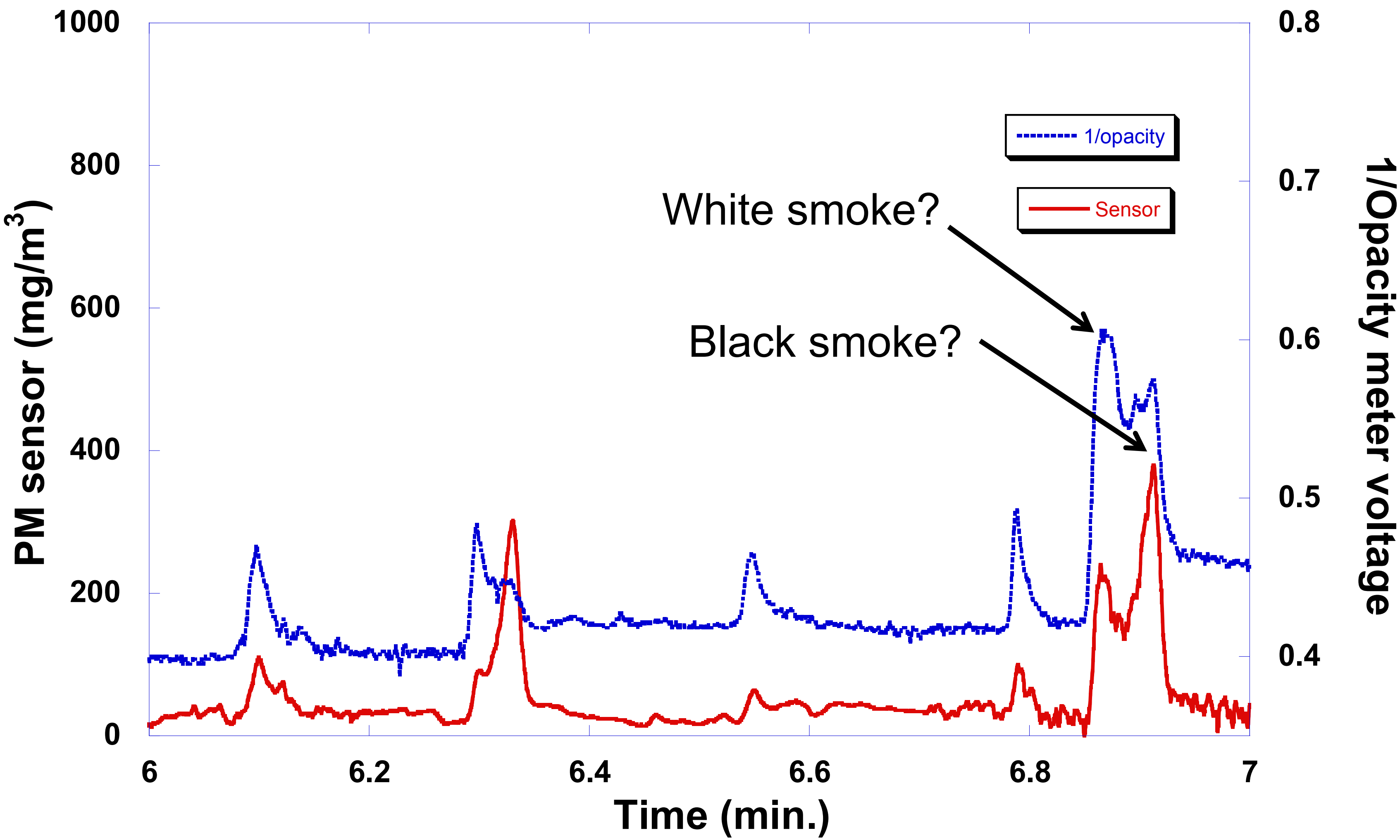
PM sensor and inverse of opacity meter

(correlation between the two at lower PM levels)

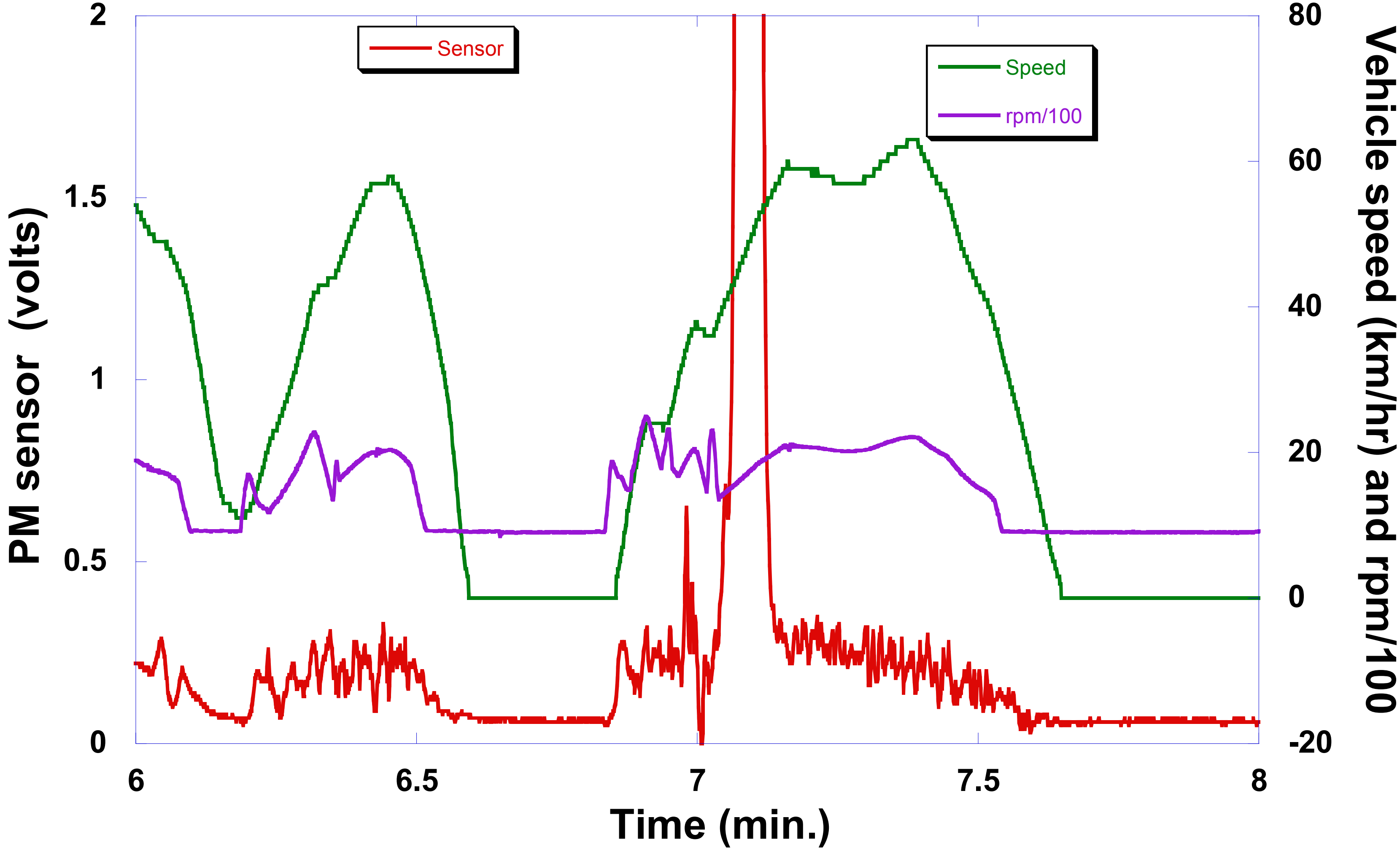


PM sensor and Inverse of opacity signals

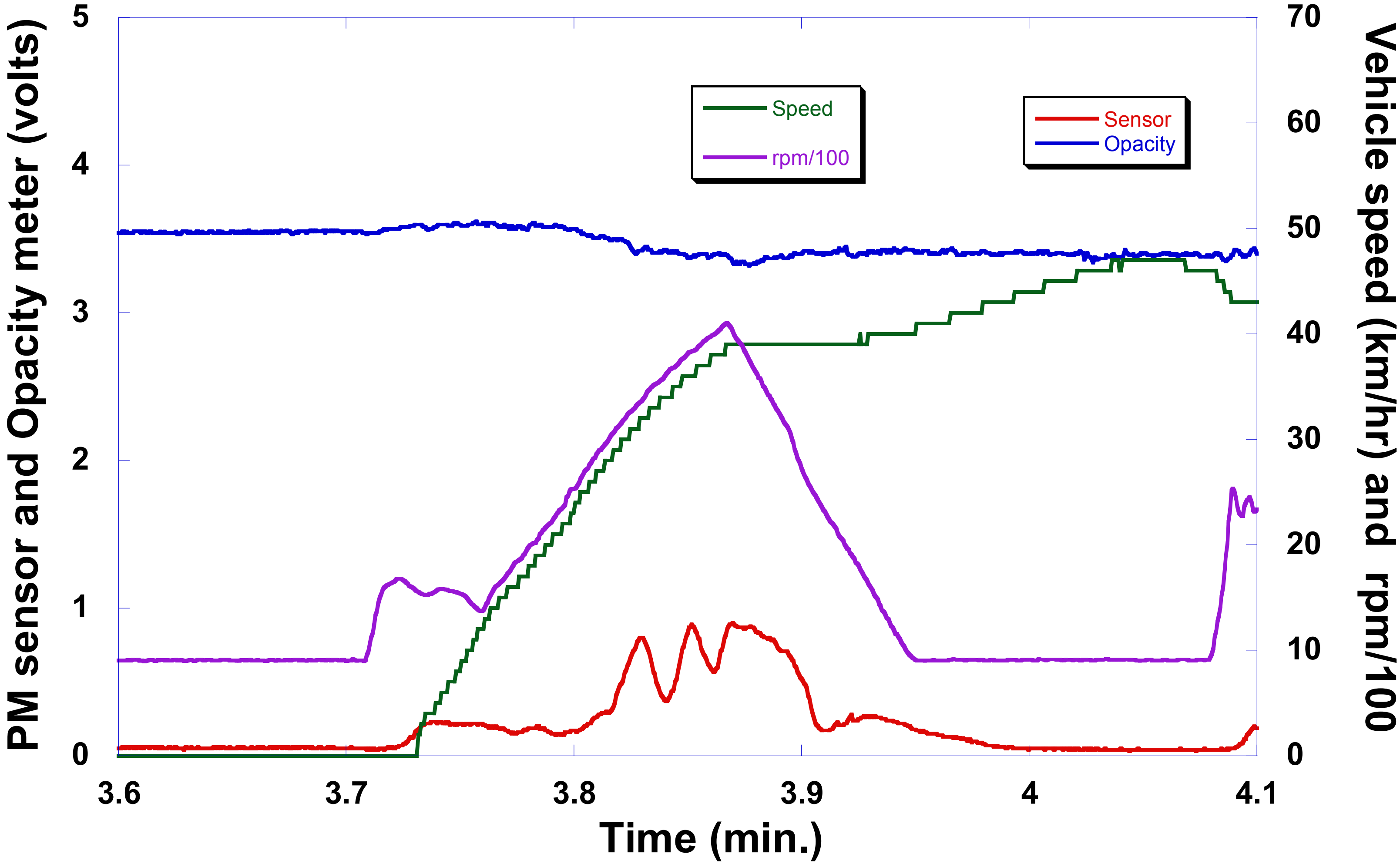
(correlation differences for twin peak signals)



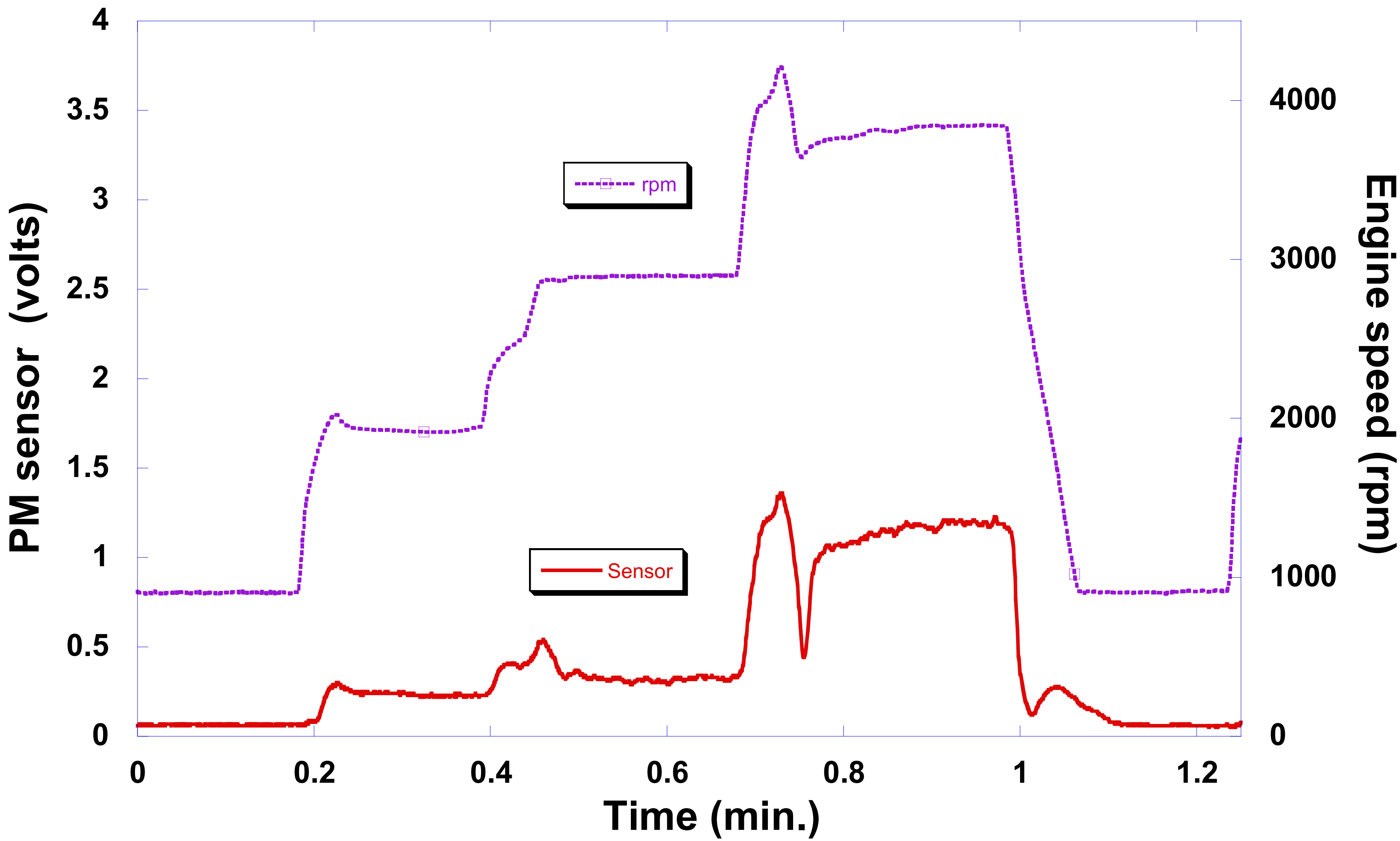
PM sensor correlation with vehicle speed and engine speed



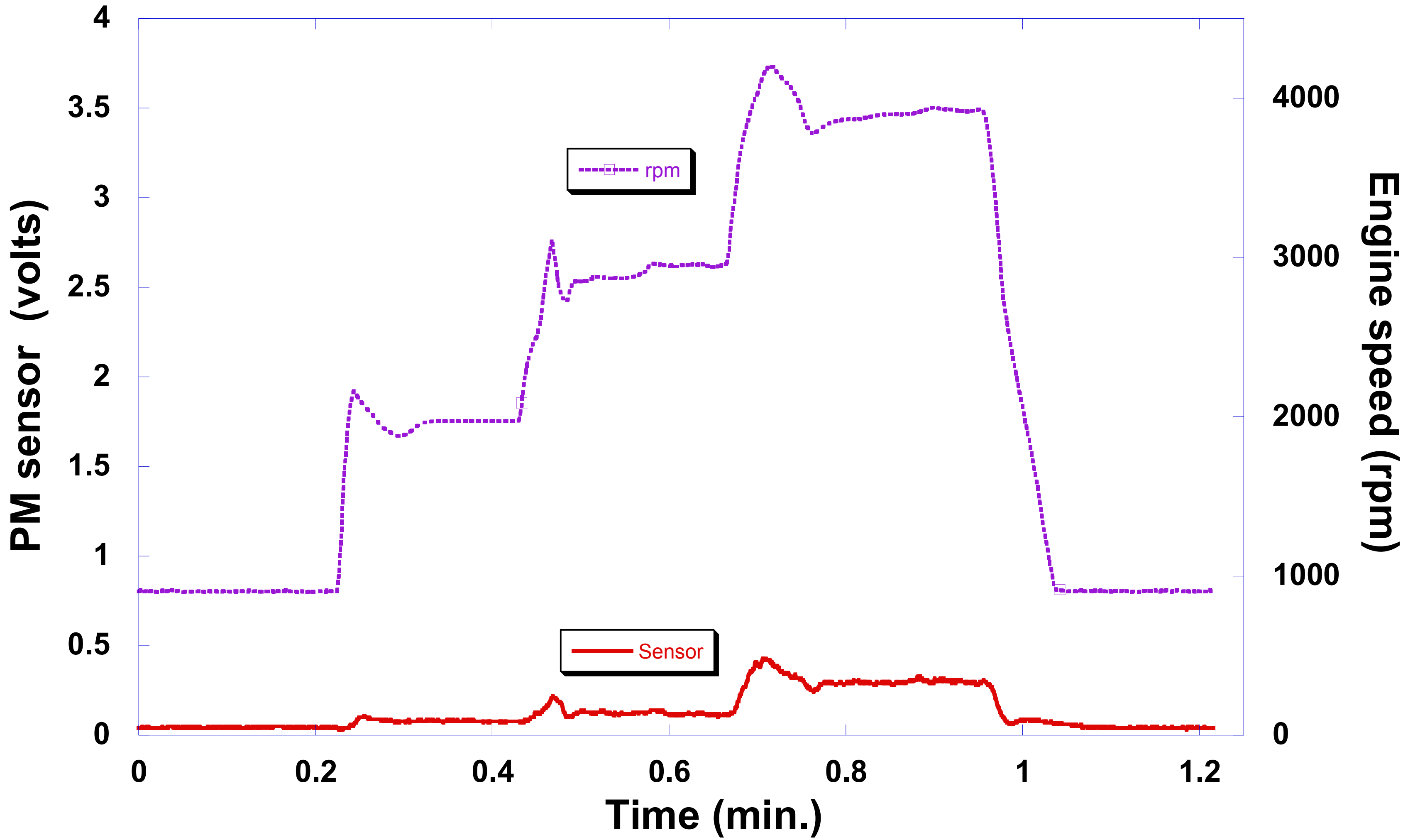
PM sensor correlation with vehicle speed and engine speed (sensor signal correlates with engine speed)



PM sensor output at different engine idle speeds (vehicle stationary)



PM sensor output at different engine idle speeds
(configuration to reduce exhaust velocity past sensor)



Future Work

- Continue development of PM sensor to further improve durability, sensitivity, and signal-to-noise ratio.
- Demonstrate PM sensor durability and response through on-board diesel vehicle studies.
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Summary

•UT PM sensor is capable of measuring time-resolved PM emissions from a diesel engine for steady-state and transient operation.

•High PM emissions, in the range of 1000 mg/m^3 were measured during hard acceleration and correlated with pedal positions greater than about 40% of maximum.

•Good correlation between sensor and opacity was also found for much lower PM levels.

•Previous Data suggest a PM concentration resolution of 3-4 mg/m^3 dry mass is attainable and dynamic range of the sensor spans at least 2.5 orders of magnitude.

•The effect of exhaust gas velocity on the sensor signal was evident by its response to changes in engine speed, both at idle and during driving.