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Assessment of a Laser-Induced Incandescence Sensor for Real-Time Particulate Emissions Measurement

Ritesh C. Gujarathi^a, Virendra Kumar^a, Shirish A. Shimpi^a, William D. Bachalo^b, and Gregory J. Smallwood^c

^a Cummins Technical Center, Cummins Inc., 1900 McKinley Ave, Columbus, IN – 47201

^b Artium Technologies Inc., 150 West Iowa Ave, Sunnyvale, Unit 202, CA – 94086

^c National Research Council, Bldg. M-9, 1200 Montreal Road, Ottawa, ON K1A 0R6, Canada

Motivation

- Support increased technical productivity by developing process technology to more effectively and efficiently estimate concentrations of particulate matter (PM) in Diesel engine exhaust
- This will enable the further development of emissions compliant engine products
 - Develop efficient and effective soot management and dosing strategy for DPF's
 - Develop effective engine calibrations for reducing PM levels at different engine conditions
 - Facilitate further development of emissions compliant engine products

Background

- Currently "Gravimetric PM Sampling System" is used to measure PM, which is not real-time
- Laser Induced Incandescence (LII) is a real time, non-intrusive soot measurement techniques for rapid characterization of diesel particulate emissions
- The LII method has the advantage of being able to sample and report particulate emissions from either the direct exhaust or from a dilution tunnel facility

Approach

- In the present investigation, the LII instrument was evaluated extensively at the Constant Volume Sampling (CVS) emission laboratory at the Cummins Technical Center, where a Cummins' standard gravimetric PM measurement system is available as a comparative standard
- Collaborative efforts between Cummins Inc. and Artium Technologies are ongoing with the goal of advancing the LII capability for measuring real time soot at pre- and post DPF locations at transient and steady state engine operating conditions

Artium LII-200 Instrument

- LII technique evaluated was developed and patented by NRC Canada
- Artium Technologies Inc. commercialized LII-200
- LII-200 has 4 sub-systems:
 - LII power supply
 - Gas Flow Controller
 - LII Sensor Head
 - On-board computer with AIMS software (Advanced Instrument Management Software)

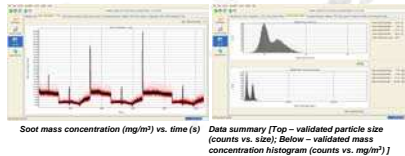


LII Advantages and Features

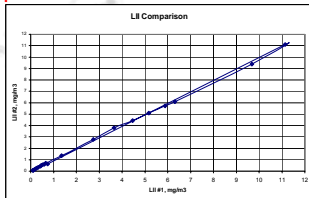
- Measures real-time soot concentration (ppb & mg/m³)
- Sample dilution not required, can be used to estimate SVF in raw exhaust

- Insensitive to presence of other emission gas species
- Data recording frequency: 1–20 Hz and connectivity with host data acquisition system
- Ease of operation, portable to transport and maintenance free working
- Absolute intensity calibration
- High resolution (0.01mg/m³) and high repeatability (2-5%)

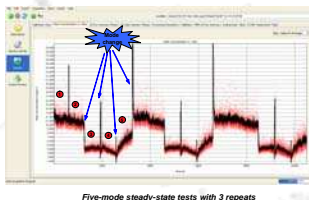
Example AIMS results from LII-200



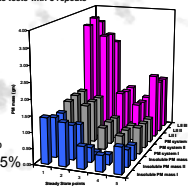
Comparison Between Two LII-200 Instruments



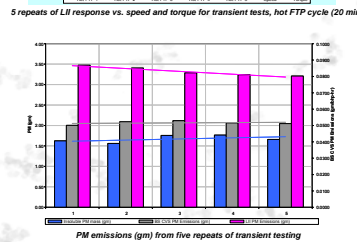
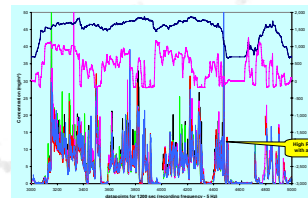
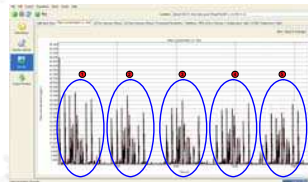
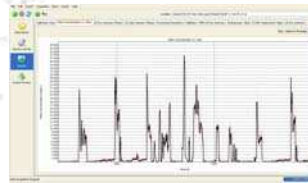
Initial LII Steady State Response



- LII steady-state response higher by ~1.7-2.5 * TPM
- Short-term steady-state repeatability (COV)
 - LII: 3-7%
 - Gravimetric TPM: 2-5%
 - SOF extracted PM: 3-25%



Initial Transient Response



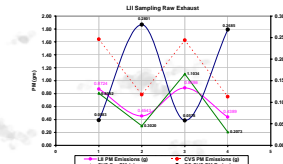
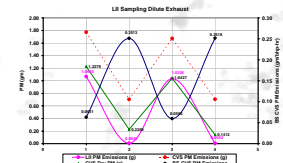
- LII transient response higher by 1.6 * TPM and 2.0 * SOF extracted PM

Short-term transient repeatability (COV)

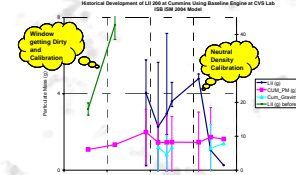
- LII: 3.5%
- Gravimetric TPM: 2.1%
- SOF extracted PM: 5.3%

Latest Results with Correct Calibration

- An issue was discovered with the neutral density filters in the LII instrument; it was recalibrated on-site
- LII now is reporting lower SVF values than TPM

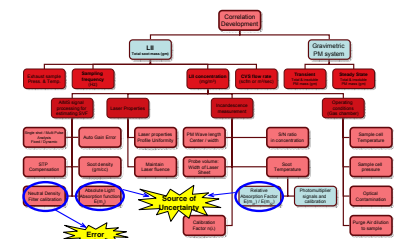


- At high load, in both diluted and raw exhausts, LII measures about 95% of Dry PM from diluted exhaust measured by the Cummins Gravimetric method
- At low load, in raw exhausts, LII measures higher (ranging from 1.1 to 3 times), and in diluted exhaust substantially lower, as compared to Dry PM from diluted exhaust measured by the Cummins Gravimetric method



- Above graph shows the historical development of LII system at Cummins. This involved combined partnership to work with Artium and NRC to resolve sampling and instrument issues including: Leak in the system, software issues, improving sampling system, correcting Neutral Density filter issues
- There is still work in progress to further refine the system to expected traceability and accuracy

Critical Parameter Measurement



- Cummins, Artium, & NRC worked during the on-site visit at Cummins (13-15 Nov'07) to identify sources of uncertainty

Summary

- LII current status:
 - The LII technique is capable of monitoring PM emissions by estimating soot concentration and primary particle size
 - The currently implemented improvements to the LII resulted in repeatable measurements of soot volume fraction from the LII with a short term Coefficient of Variation (COV) of 3-7% for steady state cycles and a COV of 3-5% for FTP transient cycles for the equivalent gravimetric PM level ranging from 0.01 to 1.00 g/bhp-hr
 - The correlation between time-integrated LII signals and the standard gravimetric PM measurement system was found to be robust with a correlation regression coefficient ranging from 96%-99.8%
 - LII has been tested for Steady States, Transients, Raw Exhaust, PM Trap-out
 - LII reported similar readings compared to Dry PM measured using Cummins gravimetric method at higher load conditions, and much lower to about 0.9 to 3 times at low load conditions
 - LII-200 is nearing readiness for Prime Testing – Expected in the near future
- Work Ahead:
 - Reliable calibration of Neutral Density filters from 3rd party laboratory
 - Determine most appropriate values of Soot Absorption Function E(mλ) and relative absorption function
 - Ongoing work to increase sensitivity through improved signal averaging and processing
 - Packaging – Feasibility of installing exhaust gas Sampling System to control volumetric flow and pressure in the sample cell