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

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## 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

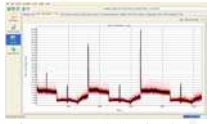
- LII technique evaluated was developed and patented by NRC Canada
- Artium Technologies Inc. commercialized LII-200
- LII-200 has 4 sub-systems:
  - –LII power supply
  - –Gas Flow Controller
  - –LII Sensor Head
  - –On-board computer with AIMS software (Advanced Instrument Management Software)



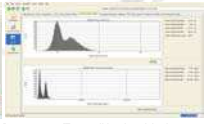
## LII Advantages and Features

- Measures real-time soot concentration (ppb & mg/m$^3$)
- 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/m$^3$) and high repeatability (2-5%)

## Example AIMS results from LII-200

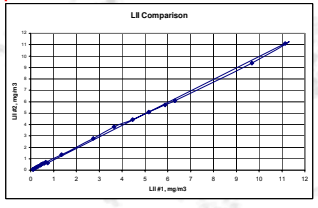


*Soot mass concentration (mg/m³) vs. time (s)*

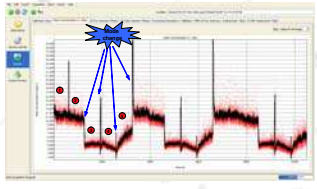


*Data summary [Top – validated particle size (counts vs. size); Below – validated mass concentration histogram (counts vs. mg/m³) ]*

## Comparison Between Two LII-200 Instruments

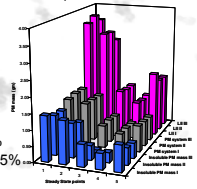



## Initial LII Steady State Response



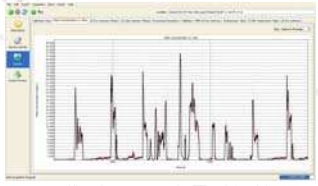
*Five-mode steady-state tests with 3 repeats*

- 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%

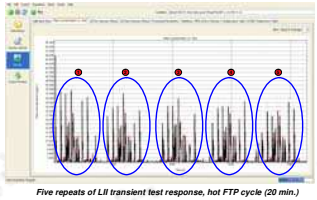


*PM mass (gm) representation for 5 mode s/s tests (with 3 repeats)*

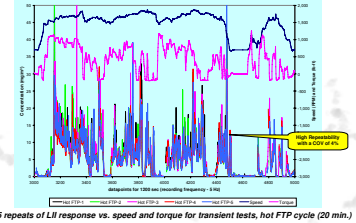
## Initial Transient Response



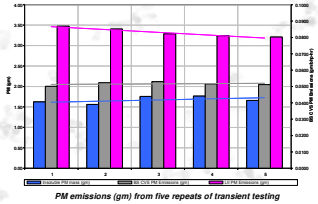
*LII transient test response, hot FTP cycle (20 min.)*



*Five repeats of LII transient test response, hot FTP cycle (20 min.)*




*5 repeats of LII response vs. speed and torque for transient tests, hot FTP cycle (20 min.)*

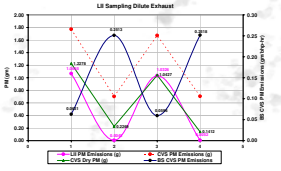


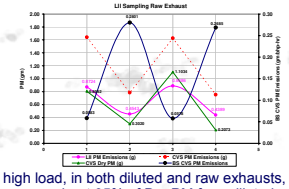
*PM emissions (gm) from five repeats of transient testing*

- 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%

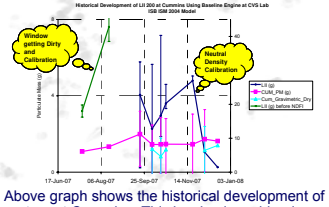
## Latest Results with Correct Calibration

- 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



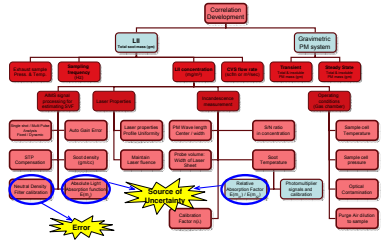




- At high load, in both diluted and raw exhausts, LII measures about 95% of Dry PM from diluted exhaust measured by the Cummins Gravimetric method
- At low load, in raw exhausts, LII measures higher (ranging from 1.1 to 3 times), and in diluted exhaust substantially lower, as compared to Dry PM from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

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