Real-time measurement of diesel nano-particulates

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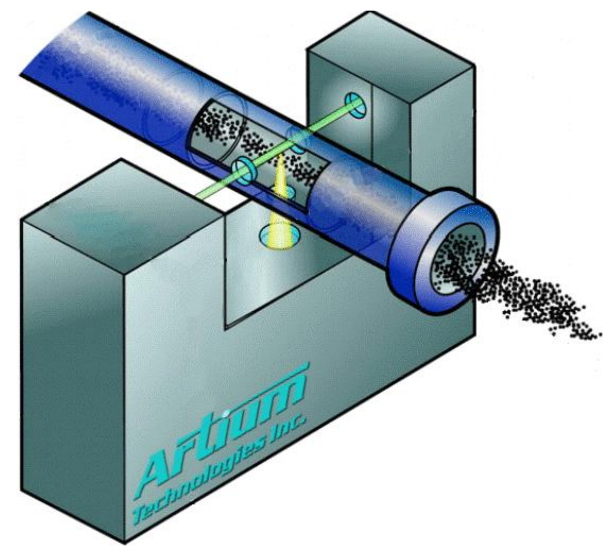
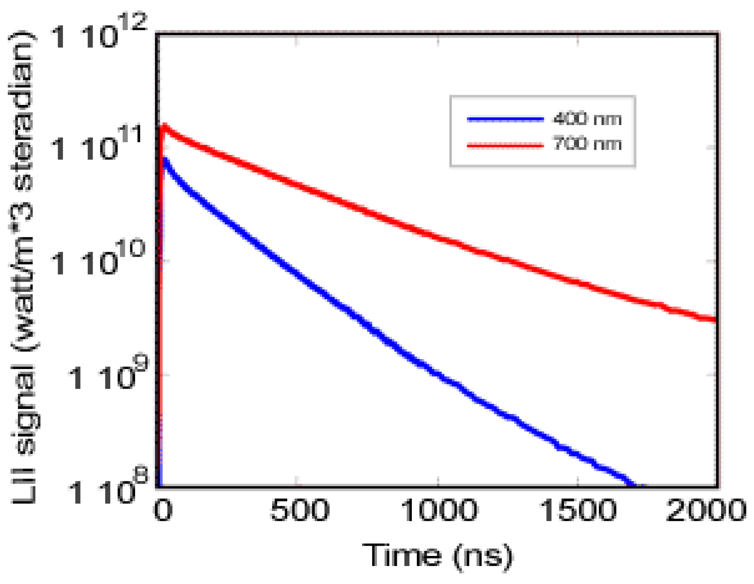
Synopsis: *During the last decade particulate matter emission regulation have mandated lower emissions. Future regulations (e.g. EURO 5) will require even lower vehicle emissions. A large reduction in total particulate mass will also create new problems in accurate measurement. Further the calibration of engine maps to interface with soot trap optimisation will require transient data which is certainly beyond current gravimetric procedures. Laser-Induced Incandescence is a technique capable of measuring accurately and near instantaneously particulate matter mass and soot primary particle diameter. LII offers as well the ability to operate in raw exhausts where hydrocarbon loading and vapours often affect other instruments.*

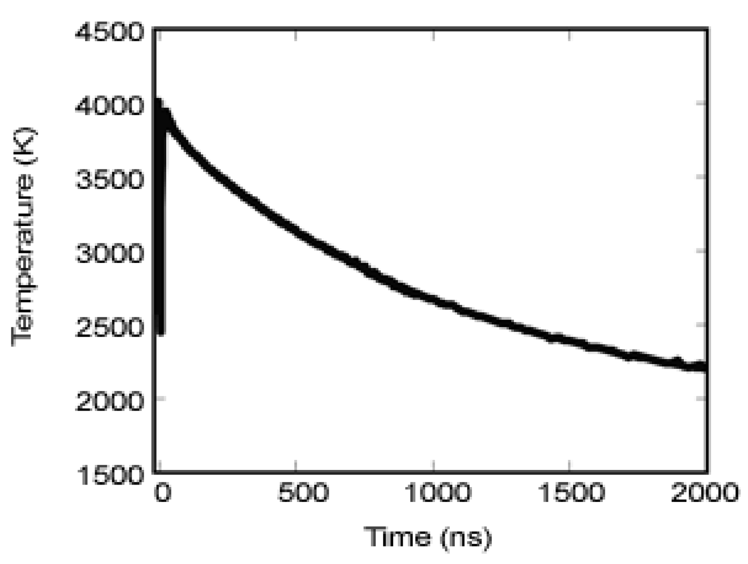
This poster presents the self-calibrated LII technique invented by the National Research Council, Canada and currently under development in collaboration with Cranfield University. We present measurements taken at Millbrook Proving Ground Emission Test Chamber on a Vauxhall Frontera® and a Dennis Dart® bus following the Euro 4 cycle procedure and the Millbrook London Bus Transport Cycle Procedure. This poster includes also a demonstration of real-time raw exhaust measurement between the exhaust and the particulate trap of a London Bus and a comparison with instruments available within the test facility.



National Research Council Canada

The Laser-Induced Incandescence (LII) Technique and the Instrument





Two-colour pyrometry is used to measure the transient cooling of primary soot particulates during LII

As a soot measurement method, Laser-Induced Incandescence (LII) occurs when a high-energy pulsed laser beam (~30 ns) encounters graphitic particulate matter particles like soot or carbon black, rising its temperature toward the sublimation point of carbon, at 3900 - 4000 K . Therefore the carbonaceous particulate matter emits measurable amounts of light through blackbody radiation during both heating and cooling.

The LII energy rate balance equation can be expressed as:

$$Q_{internal} = Q_{absorption} - Q_{radiative} - Q_{conduction} - Q_{evaporation}$$

- ***$Q_{internal}$: rate of change of the internal energy stored in the particle [$J.s^{-1}$]***
- ***$Q_{absorption}$: laser heating energy absorption [$J.s^{-1}$]***
- ***$Q_{radiative}$: radiative loss rate of energy from the particle [$J.s^{-1}$]***
- ***$Q_{conduction}$: heat loss through conduction [$J.s^{-1}$]***
- ***$Q_{evaporation}$: evaporation heat losses of the particle [$J.s^{-1}$]***

When the peak carbon temperature is kept below the sublimation limit (3200 K) the carbon particulates remain constant in size and the dominant temperature decay rate is conduction. This exponential temperature decay can be retraced using two-colour pyrometry to calculate the primary particle size:

$$T - T_0 = A \cdot e^{-t/\tau}$$

T_0 and T: ambient gas temperature and particle temperature

$$d_p = \frac{12 \cdot K_a \cdot \alpha_T}{G \cdot \lambda_{mfp} \cdot c_s \cdot \rho_s \cdot \tau}$$

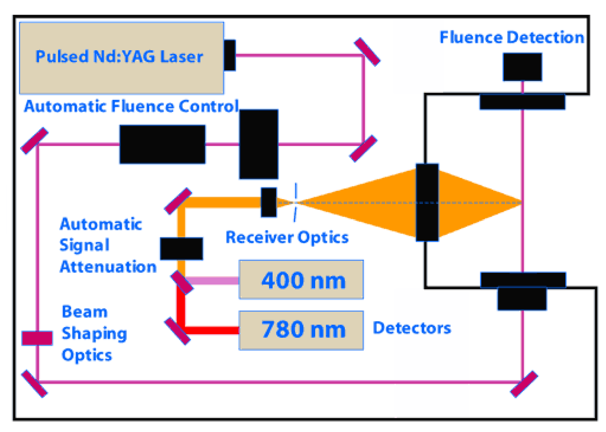
K_a [$W.cm^{-1}.K^{-1}$] : thermal conductivity of air
α_T [ ] : thermal accommodation coefficient of air
G [ ] : geometry dependent factor
λ_{mfp} [cm] : mean free path in the surrounding gas
c_s [$J.g^{-1}.K^{-1}$] : specific heat capacity of soot
ρ_s [$g.cm^{-3}$] : density of soot

Having measured the primary particle diameter, the radiation rate for one particle can be calculated, and therefore the detected light signal intensity, can be divided by the modelled signal for one primary particle, to yield the number of detected particles, N inside the measurement volume V :

$$f_v = \frac{\pi \cdot d_p^3}{6} \cdot \frac{N}{V}$$

Therefore the technique is directly correlated to an amount of light and permits a self-calibration against a radiance / irradiance standard source of light.

The self- calibrated Time-Resolved LII technique is Patented by National Research Council to Artium® who built the Artium 200® LII instrument:



The Artium 200® instrument:

Schematic of the system (top) and picture of the instrument itself (bottom)

Chassis Dynamometer measurements

Measurements were taken at Millbrook Test Centre Proving Ground Emission Test facility on Chassis dynamometer following the Euro 4 cycle and the Millbrook London Bus Transport cycle procedures. Two vehicles were tested: a Vauxhall Frontera® powered by a 2.2L DTi engine and a Dennis Dart London Bus powered by a Cummins® B130 Diesel engine.

Instruments available at Millbrook Test Centre:

TEOM

The Tapered Element Oscillating Microbalance (TEOM®) is a widely used device for measuring Particulate Matter (PM) mass in real time. A filter substrate is mounted on the tip of a hollow, tapered tube. As the filter collects material, the inertial mass increase alters the natural oscillating frequency of the tube, which is monitored continuously to give a signal proportional to the total mass of the filter. Although the signal can be monitored with high temporal resolution, the sensitivity of the device is limited by the change in mass necessary to create a detectable change in oscillating frequency.

Measurement issues with TEOM:

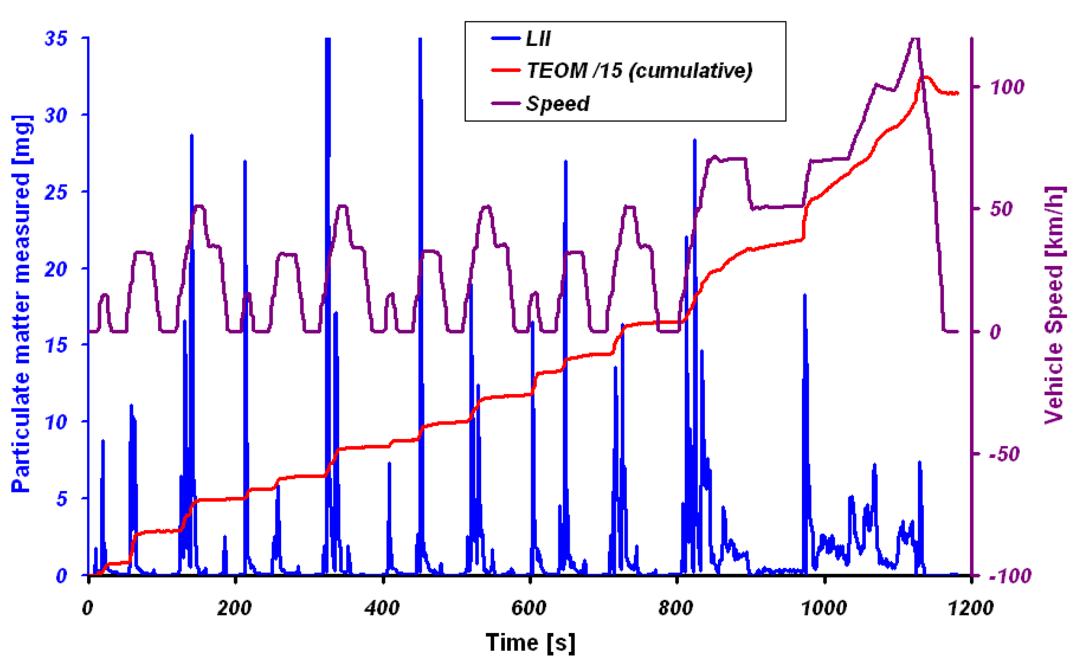
- *The TEOM is sensitive to any kind of vibration*
- *Presence of water vapour inside the TEOM measurement volume yields noise and eventually negative measurements*

ELPI

An electrical low pressure impactor (ELPI) is an inertial particle sizer particle sizer. A corona discharge is used to charge the particles with positive ions. The charged particles deposit on of the 12 impactor plates present in the system depending on their size. The current collected on each plate is read with an electrometer. The device used comprised twelve stages ranging from 0.03 to 7 microns.

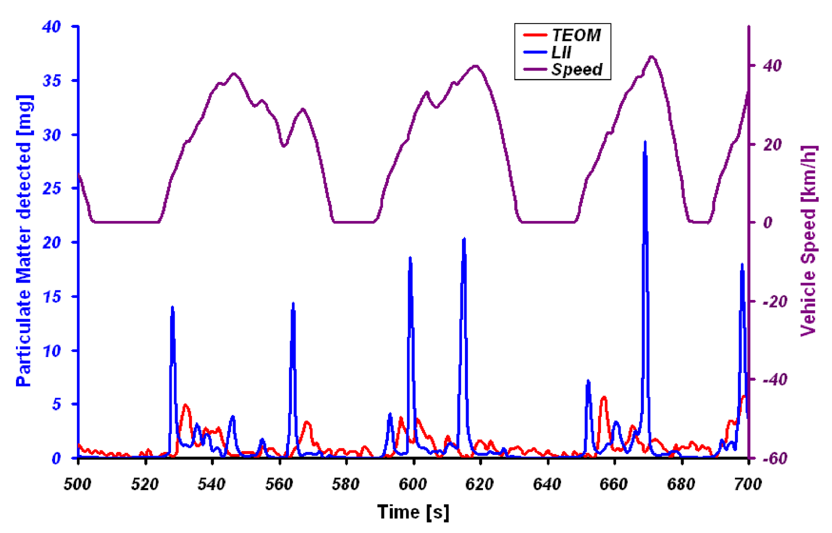
Measurement issues with ELPI:

- *The instrument measures aggregate sizes*
- *Limited number of size ranges*
- *In this case time-averaged measurements (not real-time) were done*



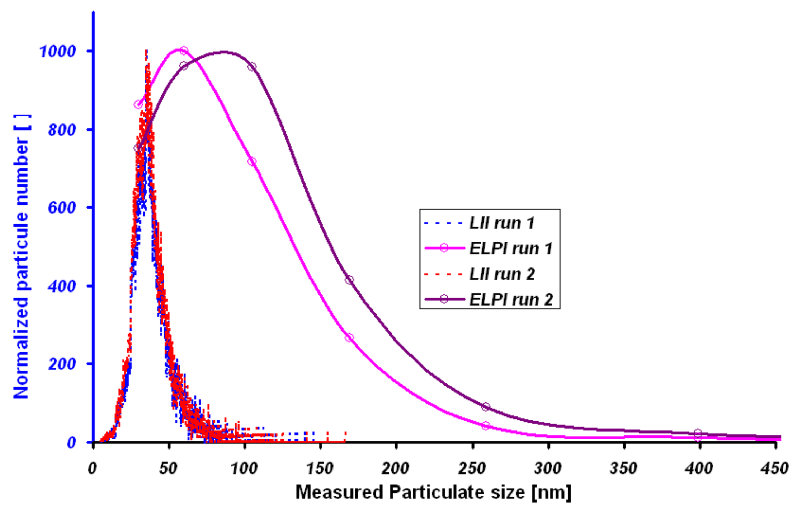
Results obtained for the Euro 4 cycle procedure on the Vauxhall Frontera® 2.2 L Dti vehicle

Intercomparison:



Comparison TEOM /LII for step changes in particulate matter mass emitted by the Vauxhall Frontera® during the London cycle procedure

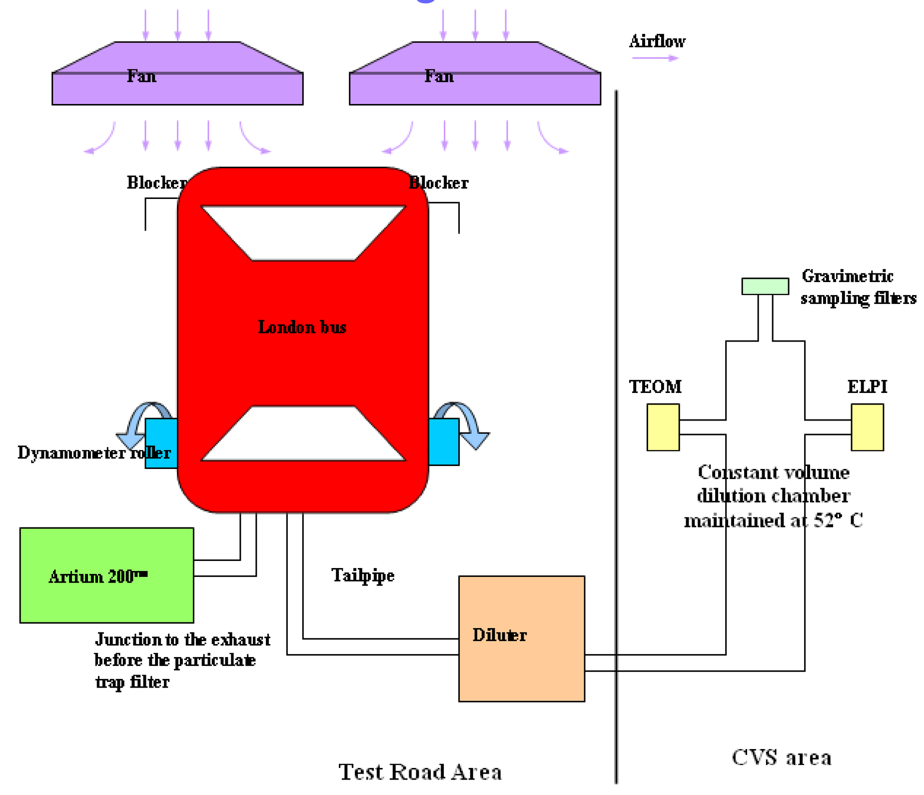
- *LII has a finer resolution and a better signal to noise ratio*
- *LII has faster time response (20 quasi – instantaneous measurements per second)*
- *LII is insensitive to water vapour (heated sampling cell), sulphuric acid and high boiling point hydrocarbon (laser heating).*



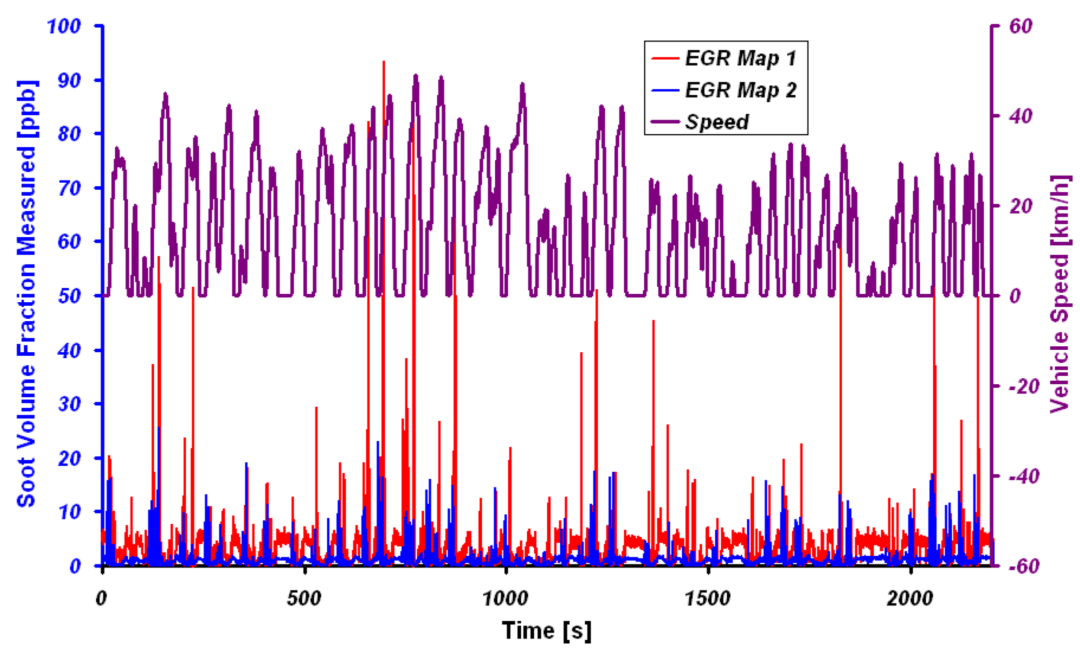
Comparison ELPI /LII for the London Bus during the Millbrook London Bus Transport cycle procedure

- *LII measures the primary particle size and has a fine resolution whereas ELPI measures aggregate size into 12 bins for the range 0.03 to 7 microns.*
- *Would LII be more repeatable or less sensitive to change in measurement conditions?*

LII was the only technique capable of real-time pre-particulate trap particulate matter measurements because it is insensitive to hydrocarbons and vapours present within the raw exhaust gases and vibrations



Test configuration for the Dennis Dart® London Bus



Results obtained for 2 different EGR (Exhaust Gas Recirculation) Maps for the London Bus during the London Bus cycle Procedure

The authors would like to acknowledge the help and assistance of Millbrook and their staff in this work.