Monitoring of Diesel Exhaust Particulate (DEP)

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Introduction

• What is Diesel exhaust particulate (DEP)?
  – Constituent of diesel engine exhaust emissions, alongside, CO, CO$_2$, NO$_x$, aldehydes, PAHs
  – 2 main components, organic carbon (OC) and elemental carbon (EC)
  – Nanoscale particles which agglomerate into clumps and chains

• Why monitor DEP?
  – IARC classify it as a definite human carcinogen
  – More specific and correlated with diesel engine exhaust emissions than the other main constituents.
Super short summary of a literature review commissioned by HSE

Health effects

• Acute – respiratory/eye irritation, rare for exposures below 100 µg/m³ EC

• Persistent - lung cancer, rhinitis and cardiac illness. Evidence is currently insufficient to establish links with adult onset asthma and COPD.
Super short summary of a literature review commissioned by HSE

Occupational exposures *(from IARC monograph, 2013)*

- Transport, typically < 50 \( \mu g/m^3 \) EC
- Mining, 100 – 600 \( \mu g/m^3 \) EC
- Construction, main exposures in tunnelling works
Super short summary of a literature review commissioned by HSE

Measurement

- EC mass by combustion is the most appropriate measurement to assess exposure to DEEEs

- Biomonitoring of nitro- and amino-pyrenes

- Increase in ultrafines (<40 nm) in modern biodiesel engines. Particulate mass (EC) may underestimate health effects
Elemental Carbon

- EC is favoured as a marker for DEP
  - Thought to be highly specific to diesel exhaust
  - Other carbon sources can be removed by size selection at the inlet
  - Some evidence that the nanoscale physical nature of the particles are a cause of observed health effects

Image courtesy of Tomas E Baquero Rincon, University of Sheffield
Established methods

• The standard method is codified in EN14530:2004 and NIOSH method 5040.

• The methods are not equivalent but incorporate the same key stages.
  – Sample on to quartz fibre filters with cyclonic samplers,
  – Heat the filter to temperature 1, measure the evolved $\text{CO}_2 = \text{OC}$.
  – Increase the temperature, measure the evolved $\text{CO}_2 = \text{EC}$
Established methods

• Being a carbonaceous soot DEP is black, therefore the degree of staining can be used to quantify exposure.

• Historically, for on-site monitoring the “blackness” of sample filters has been measured using the Bosch meter.

• Blackness can be converted to EC.
Previous work at HSL

- Alternatives to the Bosch meter
- 3 techniques analogous to measuring “blackness”
  - Difference gloss meter (DR-Lange)
  - Scanner/photo software
  - OT21 transmissometer (Magee Scientific)
- Filters collected from
  - Mobile crane exhaust
  - Ambient air in a mine
- All 3 methods could replace the Bosch meter. In principle any optical technique could be used.
Earlier work at HSL

• Charts were prepared showing the correlations between each instrument and EC.
• Functions were derived to convert the instrument results to EC.
  – Difference gloss meter
    \[ EC = 10^{(-0.0244x + 0.3196)} \]
  – Scanner (greyscale)
    \[ EC = 10^{(-0.0065x + 1.9672)} \]
  – OT21 transmissometer
    \[ EC = 10^{(0.2x - 0.0795)} \]
Modernising & Improving

- Results post shift is good but wouldn’t results during a shift be better?
  - Highlight specific exposure sources
  - Facilitate and encourage immediate interventions
  - Empower workforce
Real-time monitoring

• Incorporate pump, sampler and measurement in one device. Several options.
  – General particle counters
    • Readily available
    • Non-specific, result is number of particles not mass of EC
  – FLIR Systems Airtec
    • Developed to replicate NIOSH 5040
    • Light absorption measurement technique
    • Result given is EC based on a calibration study
  – AethLabs AE51 microaeth
    • Developed for ambient air measurement
    • Miniaturised version of OT21 measurement technique
    • Result is Black carbon
Real-time monitoring

- HSL has been studying the performance of the µAeth and Airtec in parallel sampling tests with filters analysed by EN14530.

- A controlled atmosphere of diesel exhaust has been prepared and measured in the laboratory.

- In addition the instruments have been tested in field trials in a variety of workplaces.
  - RO-RO ferries
  - Vehicle test station
  - Underground non-metal mines
Laboratory measurements

-1000
0
1000 2000
Air concentration (g/m³)
0 10 20 30 40
Time from start of test (mins)

Airtec BC

-500
0
500
1000 1500
Fitted air concentration (g/m³)
0 10 20 30 40
Time from start of test (mins)

Airtec 95% CI
BC 95% CI

HSL: HSE’s Health and Safety Laboratory

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On site measurements

1 min comparison

BC/EC (µg/m^3) vs Time

- µAeth
- Airtec
- Mine Airtec
Instrument performance

- μAeth AE51

- Airtecc
Usefulness of gas monitoring

- Measured CO, CO$_2$, NO, NO$_2$ alongside particulates.
- HSG 187 states that if CO$_2$ is <1000 ppm DEEE exposures are likely to be low. This should not be relied upon.
- CO - unmeasurable.
- CO$_2$ – confounding sources, low resolution
- NO and NO$_2$ – low resolution, can correlate with particulates, urban background often more significant
Usefulness of gas monitoring

NO2 (ppm) (Max)

CO (ppm) (Max)

NO (ppm) (Max)

CO2 (ppm) (Max)
Usefulness of gas monitoring

NO2(PPM)(Max)

NO(PPM)(Max)

CO2(PPM)(Max)

BC
Real-time monitoring - Conclusions

Airtec

- Advantages
  - Can sample for a full shift at high concentrations
  - On board display

- Limitations
  - Slow response time – not truly real time
  - High limit of detection, especially for short term sampling

AE51 microAeth

- Advantages
  - Low detection limits
  - Quick response

- Limitations
  - Short monitoring period at high concentrations
  - Does BC = EC?
  - Separate device required to view results in real-time
Summary

• Diesel exhaust is unhealthy
• Most UK occupational exposures are low
• Levels in the general environment are also significant
• Real-time monitoring is possible using black carbon as a proxy.
• Research interest globally
Improved microAeth instruments

- Now in 3 formats, two personal monitors, one static
- Tape filter drive (for extended sampling and analysis),
- Multi wavelength capabilities (allowing assessment of organic carbon, brown carbon e.g. woodsmoke/tobacco derived carbon in addition to black carbon)
- Dual spot sampling (internal correction of self absorption)
- GPS and Wifi/Bluetooth capabilities (for data transfer to PC/Tablet/phone etc.)
- Weather-proof version for fenceline/lamp post/static sampling (unattended monitoring for up to 3 months)
Acknowledgements/Further reading

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• HSE RR994, available from the HSE website


• AethLabs AE51 μAeth - www.aethlabs.com/microaeth

• FLIR Airtec - www.flir.com/airtec/
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