Ricardo
Energy & Environment

Filterable and condensable particles in the EMEP/EEA Guidebook update

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Overview

1. What are filterable and condensable particles
   - ➢ Key sectors
2. Measurement of filterable/condensable/total particles
3. EMEP/EEA Guidebook update
   - Scope of revisions
   - Sectors updated
   - Key findings
   - Examples
4. Conclusions and suggested next steps

- Project funded by European Commission
- Project supported by EEA
- Input from consultees
- Project partners: Aether & Amec Foster Wheeler

Condensable and filterable particles

- Particulate matter is made up of **filterable** and **condensable** fractions
- Filterable particulate matter is solid or liquid phase material which is trapped on a filter during measurement
- Condensable particulate matter is vapour phase material which becomes a solid or liquid particle on cooling and dilution in the atmosphere
- A measurement of particulate matter emissions may be
  - Filterable PM
  - Condensable PM
  - Total PM

TNO, TFEIP Istanbul meeting 2013

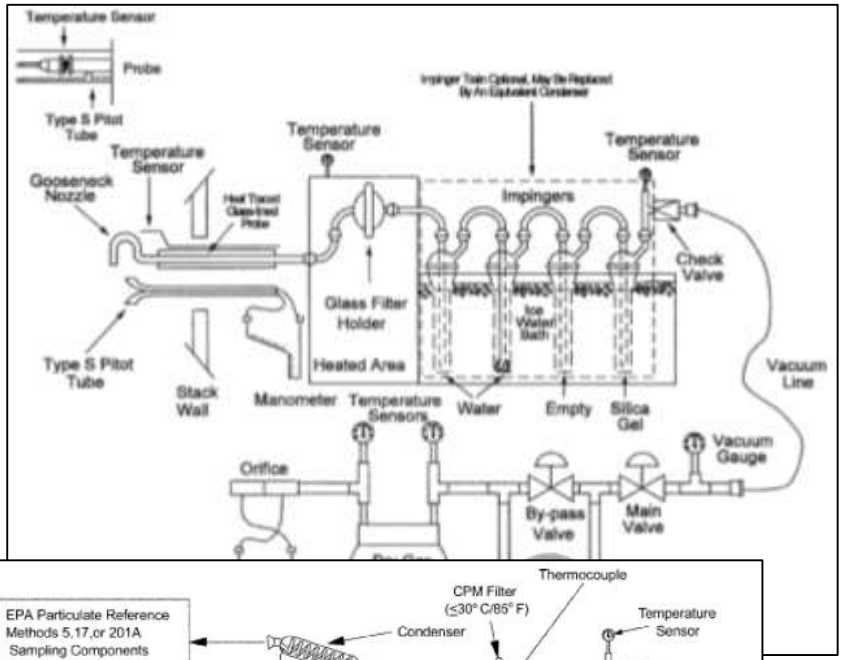
What are condensable and filterable particles?

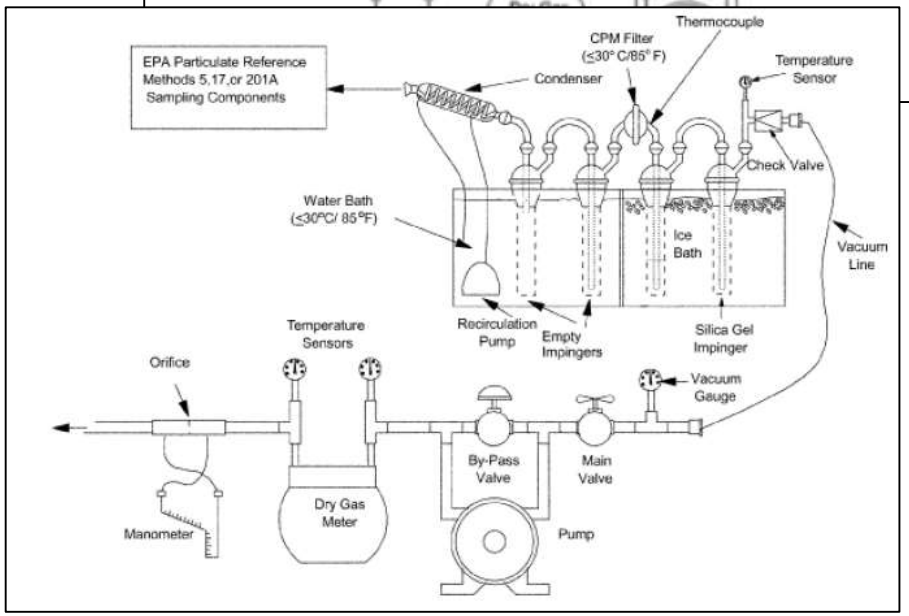
- Filterable particles are more straightforward to measure
  - Quantity collected may be affected by sample temperature and/or filter pore size
- Condensables are semi-volatile species
- Condensables may be organic or inorganic
  - E.g. products of incomplete combustion, typically long chain hydrocarbons or aromatic compounds
  - E.g. metal chlorides from ferrous metal
  - E.g. chlorides from straw or other biomass combustion
  - E.g. condensation of vapour phase metals from high temperature combustion

Sleaford straw-fired Renewable Energy Plant

Measurement of condensable & filterable particles

- Condensable particles are measured for a wide range of sources
  - Different techniques used for different applications
- Industrial sources including large combustion plant
  - US EPA method 5
    Filterable particles measured @125C
  - US EPA method 202
    Condensable particles are recorded downstream using an impinger train at 4C
  - Further downstream sample processing to remove artefacts e.g. sulphates/ nitrates using compressed air
  - Continuous method: typically optical
    Calibration is key





Measurement of condensable & filterable particles (cont.)

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Photograph: Eduwhere

Measurement of condensable & filterable particles (cont.)

- Residential combustion:
  - National standard methods, but no standard method across the EU
  - NO: Dilute flue gas before sampling – allows condensable particles to condense
  - UK: Electrostatic precipitator or ambient dilution tunnel
  - DE uses filter temperature of 70C and measures filterable particles only
- Road vehicles
  - Dilute sample following sampling – more akin to atmospheric processes.
  - Internationally recognised method based on European type approval and supporting technical regulations
  - Filter temperature of 42 - 52C

Measurement of condensable & filterable particles - summary

- Particulate emissions estimates are dependent on how the measurement is done
- Many measurements only record filterable particulates
  - US measurements from combustion processes may include condensable particulates
  - EU measurements from combustion processes likely to be only filterable
  - IED compliance likely to be calibrated against measurement of filterable PM
- Measurements using dilution method would represent total PM
  - All vehicle emissions measurements
  - Residential emissions in some countries

EMEP/EEA Guidebook Update

- 2013 Guidebook is not explicit as to whether Emission Factors for PM represent
  - Filterable PM
  - Total PM
  - Condensable PM (unlikely)
- Guidebook update
  - "*… PM EFs throughout the GB require review and labelling as condensable or filterable to ensure that users can improve consistency in their inventories*"

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EUROPEAN COMMISSION
DIRECTORATE-GENERAL
ENVIRONMENT
Directorate C - Quality of Life, Water & Air
ENV.C.3 – Air & Industrial Emissions

Continued improvements of inventory methodologies

Specific Agreement 7 under Framework Contract
ENV.C.3/FRA/2013/0013[1]

Task 2. Improving the quality of PM inventory estimates

i. Condensable vs Filterable EFs

Recent work presented at the TFEIP has highlighted the very high discrepancies (exceeding ca. 30% in some instances) in emission factors used in certain countries (e.g. between Sweden and Denmark) for the exact same sources. A main reason for the differences in the PM emission factors is that they have been derived from very different measurement techniques, some of which include the condensable fraction of particulate matter, and some of which do not. To improve the comparability of national PM emission inventories, and to improve the quality of information used in air quality modelling, there is a need review the existing information in the GB. All PM EFs throughout the GB require review and labelling as condensable or filterable, to ensure that users can improve consistency in their inventories.

EMEP/EEA Guidebook Update

- Identified key sectors for the update:
  - Sectors which may have condensable PM emissions
  - Data available to understand EFs
- Key sectors identified:
  - Residential & commercial solid fuel
  - Vehicle emissions and other engines
  - Industrial combustion (solid/liquid/gas/biomass)
- Identified and reviewed original references for EFs
  - Deduce EF basis from reference to standard methodology or description in reference document – “total PM” or “filterable PM”
  - If methodological information was not provided, this was noted as “not clear”
  - Where the project team considered that a particular metric was likely but this was not documented, this was recorded as “not clear”
  - Additional information on breakdown of total PM emissions is available for some sectors

EMEP/EEA Guidebook Update - sectors

Energy industries	1.A.1	Tables 3-2 to 3-7, 3-9 to 3-2 4-2, 4-4 to 4-8, 5-1 to 5-3
Combustion manufacturing & construction	1.A.2	Tables 3-2 to 3-5
Exhaust emissions from road transport	1.A.3.b.i-iv	Table 3-6, 3-16 to 3-19, 3-21, 3-23, 3-42, 3-43, 3-45 to 3-49, 3-56, 3-61
Small combustion	1.A.4	Tables 3-3 to 3-10, 3-12 to 3-41
Non-road mobile sources and machinery	1.A.4	[Table 3-1 and 3-2] (already specified)
Iron and steel production	2.C.1	Tables 3-1 to 3-22
Ferroalloys production	2.C.2	Table 3-1
Aluminium production	2.C.3	Tables 3-1 to 3-3
Lead production	2.C.5	Tables 3-1 to 3-10
Zinc production	2.C.6	Tables 3-1 to 3-9
Copper production	2.C.7.a	Table 3-3
Nickel production	2.C.7.b	Table 3-1
Other metal production	2.C.7.c	Table 3-1
Road paving with asphalt	2.D.3.b	Tables 3-1 to 3-4
Crop production and agricultural soils	3.D	Tables 3-1, 3-7 to 3-10

EMEP/EEA Guidebook Update - sectors

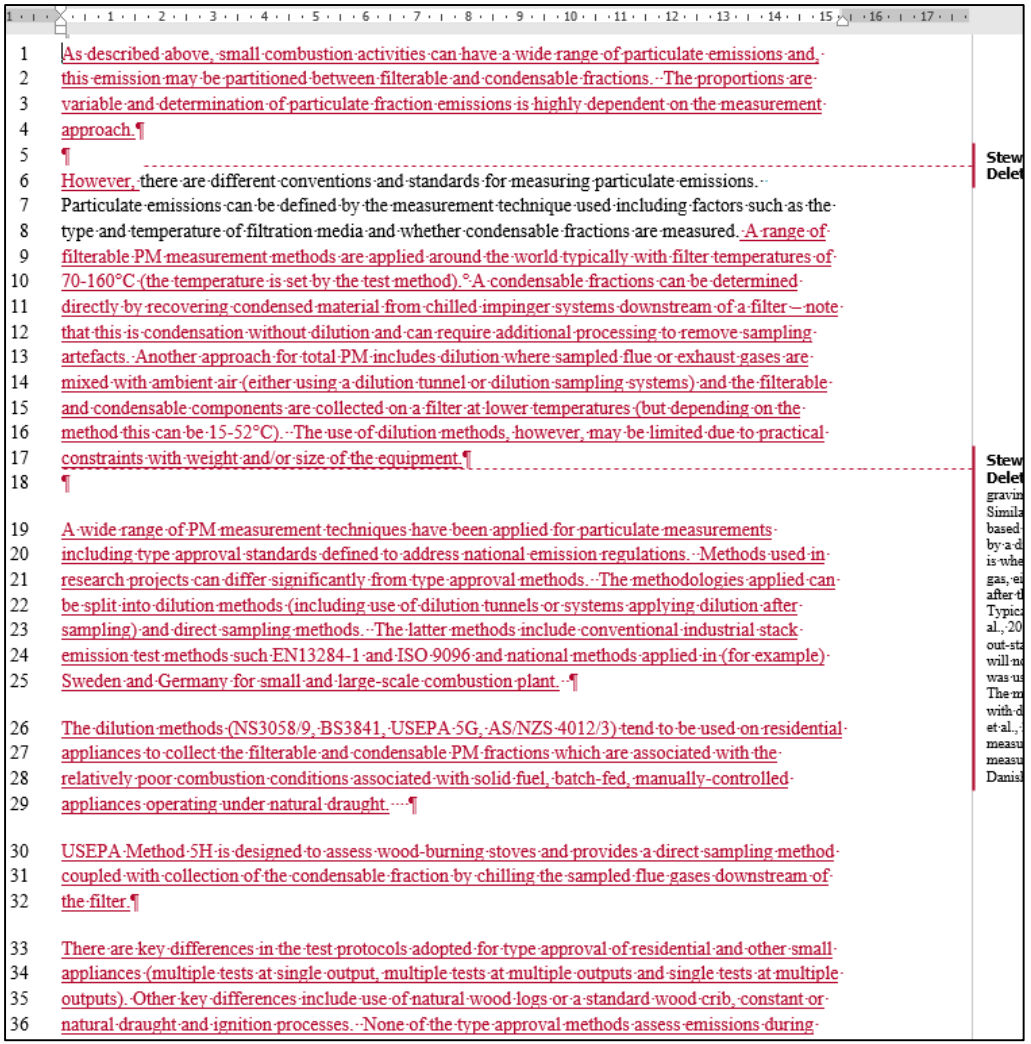
- 14 chapters updated
- Confident about what the Guidebook EFs represent in most cases
  - Energy transformation — Filterable (not necessarily specified in references) Some data uncertain
  - Refinery — Filterable
  - Transport, NRMM — Total PM
  - Metals — Majority filterable.
  - Residential combustion — Mix of total, filterable and unclear
  - Wood processing — Unclear – single old reference
- Uncertainty: sectors with potentially significant gaps:
  - Residential combustion
  - Wood processing?
  - Improvement of current position may involve additional monitoring
- Incompleteness: Sectors with potentially large condensable component, where data represent filterable only:
  - Refinery, Residential, Wood processing?

EMEP/EEA Guidebook Update: Key findings

- Improvement in data quality allows inventory compilers and modellers to understand data
- For some sectors, the basis of the EF for particulate matter is unclear.
- Measurements based on USEPA methods may have data for both filterable and condensable.
  - A lot of references are old and may not be representative of current technology.
- Inventory compilers need to understand what the EFs represent. Particularly important for domestic combustion
  - Poor/variable control of individual units
  - Relatively high contribution of condensable particles due to incomplete combustion
- Regulation requires consideration of TPM, PM_{10} and $PM_{2.5}$, but is not specific about primary or secondary particles.
  - E.g. for solid fuel appliances DE measures filterable PM, whereas NO & UK measure total emissions
- Condensable organic compounds – captured by condensable method, but may re-evaporate in the atmosphere, depending on local environment & dispersion.

EMEP/EEA Guidebook Update: Example – small scale combustion

- New description of measurement methods
  - Measurement of filterable PM
  - Dilution versus direct sampling and implications
  - Temperature regimes and implications
  - Limitations (e.g. no measurement of emissions from cold ignition)
- PM Emission Factors:
- Tier 1:
  - Not known 6 out of 8
  - Filterable 1 out of 8
  - Total 1 out of 8
- Tier 2:
  - Not known 15 out of 30
  - Filterable 10 out of 30
  - Total 5 out of 30



As described above, small combustion activities can have a wide range of particulate emissions and, this emission may be partitioned between filterable and condensable fractions. The proportions are variable and determination of particulate fraction emissions is highly dependent on the measurement approach.

However, there are different conventions and standards for measuring particulate emissions. Particulate emissions can be defined by the measurement technique used including factors such as the type and temperature of filtration media and whether condensable fractions are measured. A range of filterable PM measurement methods are applied around the world typically with filter temperatures of 70-160°C (the temperature is set by the test method). °A condensable fractions can be determined directly by recovering condensed material from chilled impinger systems downstream of a filter – note that this is condensation without dilution and can require additional processing to remove sampling artefacts. Another approach for total PM includes dilution where sampled flue or exhaust gases are mixed with ambient air (either using a dilution tunnel or dilution sampling systems) and the filterable and condensable components are collected on a filter at lower temperatures (but depending on the method this can be 15-52°C). The use of dilution methods, however, may be limited due to practical constraints with weight and/or size of the equipment.

A wide range of PM measurement techniques have been applied for particulate measurements including type approval standards defined to address national emission regulations. Methods used in research projects can differ significantly from type approval methods. The methodologies applied can be split into dilution methods (including use of dilution tunnels or systems applying dilution after sampling) and direct sampling methods. The latter methods include conventional industrial stack emission test methods such EN13284-1 and ISO 9096 and national methods applied in (for example) Sweden and Germany for small and large-scale combustion plant.

The dilution methods (NS3058/9, BS3841, USEPA 5G, AS/NZS 4012/3) tend to be used on residential appliances to collect the filterable and condensable PM fractions which are associated with the relatively poor combustion conditions associated with solid fuel, batch-fed, manually-controlled appliances operating under natural draught.

USEPA Method 5H is designed to assess wood-burning stoves and provides a direct sampling method coupled with collection of the condensable fraction by chilling the sampled flue gases downstream of the filter.

There are key differences in the test protocols adopted for type approval of residential and other small appliances (multiple tests at single output, multiple tests at multiple outputs and single tests at multiple outputs). Other key differences include use of natural wood logs or a standard wood crib, constant or natural draught and ignition processes. None of the type approval methods assess emissions during

EMEP/EEA Guidebook Update: Example – small scale combustion

- Tier 2 Emission Factors

Fuel	Sector	Technology	PM
Solid fuels (excluding biomass)	Residential	Open fireplaces	**Unclear**
Natural gas	Residential	Partly closed/closed fireplaces	**Filterable**
Wood	Residential	Open fireplaces	**Total**
Solid fuels (excluding biomass)	Residential	Conventional stoves	**Unclear**
Solid fuels (excluding biomass)	Residential	Conventional boilers <50kW	**Filterable**
Wood	Residential	Conventional stoves	**Total**
Wood	Residential	Conventional boilers < 50 kW	**Unclear**
Natural gas	Residential	Conventional boilers < 50 kW	**Unclear**
Gas oil	Residential	Conventional stoves	**Unclear**
Gas oil	Residential	Conventional boilers < 50 kW	**Filterable**
Coal	Residential	Advanced stoves	**Unclear**
Wood	Residential	Energy efficient stoves	**Total**
Wood	Residential	Advanced/Ecolabelled stoves and boilers	**Total**
Wood	Residential	Pellet stoves and boilers	**Total**
Coal	Non-residential	Standard boilers >50KWth <1MWth	**Unclear***
Coal	Non-residential	Standard boilers >1MWth <50MWth	**Unclear***
Coal	Non-residential	Boilers <1MWth – manual feed technology	**Unclear***
Coal	Non-residential	Boilers <1MWth – automatic feed technology	**Filterable**
Fuel oil	Non-residential	Standard boilers >50KWth <1MWth	**Filterable**
Fuel oil	Non-residential	Standard boilers >1MWth <50MWth	**Filterable**
Wood	Non-residential	Standard boilers >50KWth <1MWth	**Unclear***
Wood	Non-residential	Standard boilers >1MWth <50MWth	**Unclear***
Wood	Non-residential	Boilers <1MWth – Manual feed technology	**Filterable**
Wood	Non-residential	Boilers <1MWth - Automatic feed technology	**Unclear***
Natural gas	Non-residential	Standard boilers >50KWth <1MWth	**Filterable**
Natural gas	Non-residential	Standard boilers >1MWth <50MWth	**Filterable**
Natural gas	Non-residential	Gas turbines	**Unclear***
Gas oil	Non-residential	Gas turbines	**Unclear***
Natural gas	Non-residential	Stationary reciprocating engines	**Unclear***
Gas oil	Non-residential	Stationary reciprocating engines	**Filterable**

EMEP/EEA Guidebook Update: Example – 1.A.3.b.i-iv: Road transport

- All PM emission measurements use a dilution technique
- Hence all emission factors are representative of test procedures which include the PM concentrations in the condensable fraction of exhaust emissions.
  - i.e. Total PM
- There is flexibility in the temperature of the dilution system (42 - 52C)
  - Sensitivity analysis may be useful

Ricardo vehicle emission test centre, Shoreham, UK

EMEP/EEA Guidebook Update: Example – 1.A.1.a Public electricity and heat production; 1.A.1.b Petroleum refining

- Classification of PM Emission Factors
- Tier 1:
  - Filterable Electricity/heat: 6 Refinery: 1
  - Condensable also available from USEPA references
- Tier 2:
  - Not known Electricity/heat: 4 Refinery: 0
  - Filterable Electricity/heat: 8 Refinery: 5
  - Total Electricity/heat: 0 Refinery: 0
  - Condensable also available from USEPA references

- Additional information
  - Tier 1/2 Refinery emissions: Classification as Filterable is deduced from a separate reference
  - Condensable PM are relevant for many refinery activities
  - Emission Factor for total PM could theoretically be deduced where data are available for both filterable and condensable

Conclusions and suggested next steps

- Re-determination of EFs for key sectors where the basis of the EF is not known
  - Wood processing
  - Metals manufacturing
  - May entail analysis of compliance monitoring data from regulated processes, or new measurements
- Further evaluation of condensable PM emissions for key sectors:
  - Refinery
  - Residential
  - Wood processing?
- National inventory compilers need to check to understand the basis of EFs
  - More clarity in 2016 GB update
  - Communicate to inventory users e.g. modellers
- Care may be needed in interpretation of data in relation to emissions ceilings

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