



Ricardo
Energy & Environment

Better Air Quality 2018

Air quality management and climate change

Characterizing particulate matter in industrial process emissions

Dr Mark Broomfield, Associate Director

Characterizing particulate matter in industrial process emissions

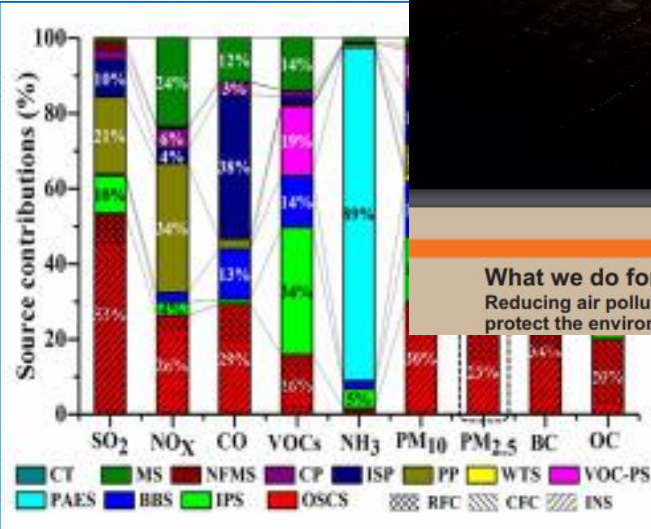
Content:

1. Emission inventories and reporting guidance
2. The problem
3. Categories of particulate matter
4. Accurately reporting particulate matter emissions



Characterizing particulate matter in industrial process emissions

- Many countries produce air emissions inventories
 - To fulfil legal reporting obligations
 - To support policy development
 - To support environmental management and research
- Typically obtained from [Activity] × [Emission Factor]
- The EMEP-EEA Emissions Inventory Guidebook provides Emission factors for signatories to the Gothenburg convention on Long-Range Transboundary Air Pollution
- Many factors provided for total suspended particulates (TSP), PM₁₀, PM_{2.5}, PM₁ and black carbon



Characterizing particulate matter in industrial process emissions

- <https://www.eea.europa.eu/publications/emep-eea-guidebook-2016>

Table 3-2 Tier 1 emission factors for 1.A.2 combustion in industry using solid fuels

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	1.A.2	Manufacturing industries and construction			
Fuel	Solid Fuels				
Not applicable					
Not estimated	NH3				
Pollutant	Value	Unit	95% confidence interval		Reference
			Lower	Upper	
NOx	173	g/GJ	150	200	Guidebook (2006) chapter B216
CO	931	g/GJ	150	2000	Guidebook (2006) chapter B216
NMVOG	88.8	g/GJ	10	300	Guidebook (2006) chapter B216
SOx	900	g/GJ	450	1000	Guidebook (2006) chapter B216
TSP	124	g/GJ	70	250	Guidebook (2006) chapter B216
PM10	117	g/GJ	60	240	Guidebook (2006) chapter B216
PM2.5	108	g/GJ	60	220	Guidebook (2006) chapter B216
BC	6.4	% of PM2.5	2	26	See Note
Pb	134	mg/GJ	50	300	Guidebook (2006) chapter B216
Cd	1.8	mg/GJ	0.2	5	Guidebook (2006) chapter B216



Characterizing particulate matter in industrial process emissions

- The problem:
 - European Environment Agency:
“There are significant differences in PM emission factors between reporting countries. A main reason for the differences in the PM emission factors is that they have been derived from different measurement techniques, some of which include the condensable fraction of particulate matter, and some of which do not.”
 - Guidebook provides emission factors for a range of emission sectors and processes.
 - Emission factors reflect measurement methods and hence some activities include condensable emissions, others don't

Characterizing particulate matter in industrial process emissions

- For example....
 - Residential stoves:
 - German measurement standard: undiluted sample with filter heated to 70°C, does not include condensable particulates
 - Norwegian measurements for wood stoves: samples are diluted at low temperature and do include condensable products
 - USEPA has two methods for wood stoves: both include condensable material
 - Transport:
 - samples are diluted at low temperature and do include condensable products
 - For industry:
 - European and ISO standard for PM do not include condensable material
 - USEPA methods allow determination of filterable and condensable fractions.

Characterizing particulate matter in industrial process emissions

- The quantity of PM determined in an emission measurement depends to a large extent on the measurement conditions.
 - This is particularly true of activities involving high temperature and semi-volatile emission components
 - PM emissions may be partitioned between a solid/aerosol phase and material which is gaseous at the sampling point but which condenses in the atmosphere.
 - The proportion of filterable and condensable material depends on the temperature of the flue gases and in sampling equipment.
- A range of filterable PM measurement methods are applied around the world typically with filter temperatures of 70-160°C
- Condensable fractions can be determined
 - Directly by recovering condensed material from chilled impinger systems downstream of a filter
 - Indirectly by dilution with ambient air, and collection of the filterable and condensable components on a filter at lower temperatures

Characterizing particulate matter in industrial process emissions

- Example: Difference between Filterable and Total particulate matter (USEPA AP42).

Activity	Units	Total	Filterable
Natural gas (boilers/furnaces)	lb/million cubic feet	7.6	1.9
“No 6” oil (assumes 1% Sulphur)	lb/thousand gallons	13.9	1.5

- Example: Difference between Filterable and Total PM_{2.5} (EMEP/EEA Guidebook 2016)

Activity	Units	Total	Filterable
Open fireplace burning wood	g/GJ heat input	820	240
Stove burning wood	g/GJ heat input	370	140
Wood pellet stove	g/GJ heat input	60	30

Characterizing particulate matter in industrial process emissions

- The problem:

- European Environment Agency:

“There are significant differences in PM emission factors between reporting countries. A main reason for the differences in the PM emission factors is that they have been derived from different measurement techniques, some of which include the condensable fraction of particulate matter, and some of which do not.”

- The solution:

- *“PM emission factors for selected activities in the Inventory Guidebook were reviewed and labelled as condensable or filterable, to ensure that users can improve consistency in their inventories.”*

- Most appropriate metric depends on the purpose:

- Calculating PM as emitted:

Filterable

- Calculating total PM burden in the atmosphere:

Total

Characterizing particulate matter in industrial process emissions

Table 3-5 Tier 1 emission factors for I.A.2 combustion in industry using biomass

Tier 1 default emission factors					
	Code	Name			
NFR Source Category	1.A.2	Manufacturing industries and construction			
Fuel	Biomass				
Not applicable					
Not estimated					
Pollutant	Value	Unit	95% confidence interval		Reference
			Lower	Upper	
NO _x	91	g/GJ	20	120	Lundgren et al. (2004) ¹⁾
CO	570	g/GJ	50	4000	EN 303 class 5 boilers, 150-300 kW
NM VOC	300	g/GJ	5	500	Naturvårdsverket, Sweden
SO ₂	11	g/GJ	8	40	US EPA (1996) AP-42, Chapter 1.9
NH ₃	37	g/GJ	18	74	Roe et al. (2004) ²⁾
TSP	150	g/GJ	75	300	Naturvårdsverket, Sweden
PM ₁₀	143	g/GJ	71	285	Naturvårdsverket, Sweden ³⁾
PM _{2.5}	140	g/GJ	70	279	Naturvårdsverket, Sweden ³⁾
BC	28	% of PM _{2.5}	11	39	Goncalves et al. (2010), Fernandes et al. (2011), Schmidl et al. (2011) ⁴⁾
HCB	5	µg/GJ	0.1	30	Syc et al. (2011)

- 1) Larger combustion chamber, 350 kW
- 2) Assumed equal to low emitting wood stoves
- 3) PM₁₀ estimated as 95 % of TSP, PM_{2.5} estimated as 93 % of TSP. The PM fractions refer to Boman et al. (2011), Pettersson et al. (2011) and the TNO CEPMEIP database.
- 4) Assumed equal to advanced/ecolabelled residential boilers
- 5) If the reference states the emission factor in g/kg dry wood the emission factors have been recalculated to g/GJ based on NCV stated in each reference. If NCV is not stated in a reference, the following values have been assumed: 18 MJ/kg for wood logs and 10 MJ/kg for wood pellets.
- 6) The TSP, PM10 and PM2.5 emission factors represent filterable PM.

Characterizing particulate matter in industrial process emissions

- 1.A.1.a Electricity & heat production **Filterable** – but condensable also available. Except for:
 - Fluidised bed coal: **Not known**
 - Recip engines natural gas: **Not known**
- 1.A.1.b Gasoline production **Filterable**
- 1.A.1.c Solid fuel manufacture **Not known**
- 1.A.2 Industrial combustion **Not clear.** Except for:
 - Biomass: **Filterable**
- 1.A.4 NRMM **Total Filterable + Condensable**
- 1.A.4.b Residential combustion **Not clear.** Except for:
 - Biomass **Filterable**
 - Solid fuel boilers **Filterable**
 - Wood fired stoves **Total Filterable + Condensable**
 - Liquid fuel boilers **Filterable**

Characterizing particulate matter in industrial process emissions

- 1.A.4.a.i Commercial combustion **Not clear.** Except for:
- 1.A.4.c.i Agricultural combustion **Not clear.** Except for:
- 1.A.4.e Other combustion **Not clear.** Except for:
 - Biomass: **Filterable**
 - Coal fired automatic boilers **Filterable**
 - Wood fired manual boilers **Filterable**
 - Gas oil fired engines **Filterable**

Characterizing particulate matter in industrial process emissions

- Black carbon
 - Regulated under the LRTAP Convention
 - 6.4% of $PM_{2.5}$ emissions from industrial solid fuel combustion
 - 4.0% of $PM_{2.5}$ emissions from industrial natural gas combustion
 - 56% of $PM_{2.5}$ emissions from industrial liquid fuel combustion
 - 28% of $PM_{2.5}$ emissions from industrial biomass combustion
 - 3% of fugitive $PM_{2.5}$ emissions from cement processing
 - 0.46% of fugitive $PM_{2.5}$ emissions from lime manufacture
 - ...
- Elemental carbon assumed to be equivalent to black carbon
 - Light-absorbing & refractory
 - Reasonable but not exact

Characterizing particulate matter in industrial process emissions

Conclusions

- Emission inventories are essential for air quality management, compliance with international commitments etc
- PM emission measurements may be filterable, condensable or {filterable + condensable}
 - And definitions depend on test methods used
- The metric used can have a significant effect on calculated emissions
- Published emission factors include a mix of metrics
- We have classified emission factors produced for UNECE LRTAP convention
 - A number of factors remain unclear
 - Particularly older references