Chemical and physical properties of biomass combustion aerosols

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ILMARI - Aerosol physics, chemistry and toxicology research unit
ILMARI research infrastructure offers versatile possibilities for studies on characteristics of emissions and aerosol particles, their atmospheric effects and toxicological properties.

Fig 1. Schema of the ILMARI Research Unit
www.uef.fi/ilmari
Exposure

Properties:

Combustion particles are usually agglomerates composed of small primary particles or rods, needles, nanotubes...

- Agglomerate size and conc. (lung deposition)
- Primary particle size (translocation...)
- Surface properties (toxic effects...)

Schematic structure of an agglomerate in 2-dimensional space.

Scanning down to view ever higher magnification
Combustion aerosol sampling and physico-chemical properties
Sampling and dilution techniques

Compact and fully adjustable diluting sampling setup for combustion exhaust measurements

- Based on the combination of porous tube diluter and ejector diluter

Tissari et al. (2008) *Energy & Fuels*; Sippula et al. (2012) *Aerosol Science & Technology*
**PM Chemical composition:**
- Thermal-optical carbon analysis, TOC (Sunset)
- GC-MS (Agilent)
- TEM-EDS (Jeol)
- SEM-EDS (Zeiss)
- X-ray diffraction, XRD (Bruker)
- ICP-MS (w. Eurofinns)
- Ion chromatography (w. Eurofinns)
- Raman spectroscopy: (Bruker)
- Sp-AMS-ToF (Aerodyne)

**PM Physical properties:**
- Scanning mobility particle sizer, SMPS (TSI)
- Fast mobility particle sizer, FMPS (TSI)
- Electrical low pressure impactor, ELPI (Dekati)
- Dekati low pressure impactor, DLPI (Dekati), PM10 impactors (Dekati)
- Nanoparticle surface area monitor, NSAM (TSI)
- Tapered element oscillating microbalance, TEOM (Thermo Scientific)
- Aerosol particle mass analyzer, APM (Kanomax)

**Gas-phase composition:**
- FTIR (Gasmet) Multicomponent analyzer
- ABB single component gas analyzers (O2, CO, NO, NO2, THC)
- PTR-ToF (Ionicon) w. Physics department
- GC-MS (Agilent)

**Modeling:**
- Computational Fluid Dynamics (CFD, Ansys)
- Thermodynamic Equilibrium (FactSage)
- Aerosol Dynamics Modeling (KCAR-code)
Batch-wise operated wood-fired appliances
Continuously operated wood-fired appliances
Gasification combustion technology
Grate boilers, pellets (no filtration)
Grate boilers, wood residues (ESP)
Gasification combustion technology, wood residues
Heavy fuel oil boilers
Fluidized bed peat & wood, pulverized coal

Emission factors:

- Residential heating
- Small district heating facilities
- CHP plants (large)

Sources:
- Tissari et al., 2009
- Tissari et al., 2003
- Sippula et al., 2007
- Tissari et al., 2008
- Lamberg et al., 2009
- Nuutinen et al., 2009
- Raunemaa et al., 2005
- Sippula et al., 2009a
- Sippula et al., 2009b
- Sippula et al., 2009c
- Ohlström et al., 2006
Methodologies: Combustion units

Field measurements

Grate fired heating plants 1-15 MW

Sippula et al. (2014) *Environ. Sci. Technol*
ELPI, number size distributions

![ELPI Size Distribution Graph](image-url)
Chemical composition: Grate boiler, wood residues

PM1.0 chemical composition:
PM1 Chemical Composition:
Grate boiler (0.5 MW), Stem-bark pellets

Thermodynamic equilibrium calculation (FactSage)
Modern continuously operated small-scale wood boiler:

Modern medium scale biomass boiler
Physical and chemical properties of PM from wood combustion

Fine particle (PM1) composition:

Leskinen et al. (2014) Atmos. Environ.
Torvela et al. (2014) Atmos. Environ.
Gasification-combustion
- Small scale fixed-bed counter-draft gasifying pellet burner
- Designed to replace oil burner using the old boiler system
- Staged primary/secondary/tertiary air feeding with a single fan

Particle size distribution

GMD = 38 nm

-Fine particle density 1000-1300 kg / m³
-Measured with APM
Inhalation exposure: Lung Total Deposition Fraction \((=DF)\); Head-Airways Deposition Fraction \((DFHA)\); Alveoli area Deposition Fraction \((DFAL)\) ja Thetra-Bronchial Deposition Fraction \((DFTB)\) as a function of particle size.
Batch-wise operated, wood log fired closed fireplace, stoves & boilers
Variation of fine PM properties in residential wood combustion

Diluting
Sampling

Soot Particle Aerosol Mass Spectrometer (SP-AMS)

Residence chamber

APM

CPC

DMA

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Physical and chemical properties of PM from wood combustion

Fine particle (PM1) composition:

- other ash species
- Cl
- Na
- SO4
- Zn
- K
- OC
- EC

Tissari et al. (2009) *Atmos. Environ.*
Leskinen et al. (2014) *Atmos. Environ.*
Variation of fine PM chemical composition in wood combustion

Leskinen et al. (2014) *Environ. Sci. Technol*
Physical and chemical properties of PM from wood combustion

Main combustion phase:

Diesel soot

Char combustion phase:

Organic rich combustion (High OC/EC):

Conclusions on the formation and properties of biomass combustion emission fine and nanoparticles

**Efficient combustion:**
- Ash containing particles in the size range of 10-200 nm
- Multi-element non-spherical particle type (see image A) most typical
- No soot particles.
- May contain e.g. ZnO core 10-30 nm

**Poor combustion:**
- Large chained soot agglomerates in the size range from 50 nm to 1 µm
- Elemental analysis show K, S and O with the soot particles
- Primary particles spherical with graphite layers (EC)

**Medium combustion:**
- Both ash and soot containing particles in the wide size range from 10 nm to 1 µm.
- Ash mostly in separate phase, but some loosely attached with soot
- Particles consisted of wide range of elements and had different morphologies
RWC soot oxidation: experimental setup and new results, Lamberg, Sippula, Tissari, Jokiniemi
Particle size change (nm) vs. Furnace peak temperature (°C)

- 200 nm Wood pellet combustion PM 50% of EC
- 100 nm Wood pellet combustion PM 50% of EC
- 40 nm Wood pellet combustion PM 50% of EC
- 130 nm Diffusion flame soot with iron doping Kim et al. 2005
- 100 nm Wood stove combustion PM 15-50% of EC
- 130 nm Diffusion flame soot Kim et al. 2005

PM 50% of EC refers to the percentage of elemental carbon (EC) in the particulate matter (PM).
SOA Photochemical flow tube reactor

- **Similarity with PAM tube**
  - 254 nm UV lamps (70 W) with adjustable power
  - External O3 feeding
  - Outlet divided to "ring flow" and center-flow

- **Flow field optimized with a diffuser inlet**
  - Design aided with 3D CFD simulations (Ansys Fluent) and trace gas experiments
  - Very low particle losses: for 50 nm particles 1-10% losses (in PAM-tube ~ 60%)

- **Stainless steel, volume 100 dm³, vertically positioned**
  - Typical flow rates 50-200 lpm -> 0.5-2 min residence time

- **Adjustable OH-exposure**
  - ~ $10^9$–$10^{12}$ molec cm$^{-3}$ s
  - Online monitoring of photochemical age via D9-butanol according to Barmet et al. (2012)

- **Other “nice-to-know”**
  - Possibility to develop the setup for low temperatures (< 0 °C)
  - Possibility to use different dilution techniques and conditions
  - Possibility to implement photochemistry models in the 3D CFD model
  - Tested so far with:
    - Toluene precursor
    - Small-scale wood combustion
    - Modern gasoline engine

Fig. A) Numerically simulated streamlines and B) the simulated and measured residence times of CO$_2$ trace gas in the photochemical flow tube reactor

For more information on SOA visit Poster 24 Sippula et al. and Hear Leskinen et al. talk tomorrow morning
Thank You for Attention

www.uef.fi/fine