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FINE PARTICULATE EMISSIONS FROM STATE-OF-THE-ART SMALL-SCALE AUSTRIAN PELLET FURNACES

CHARACTERISATION, FORMATION AND POSSIBILITIES OF REDUCTION

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Contents

Intention of the project (I)

- During the last years fine particulate air pollution (PM_{10}) has become a topic of broad public awareness since it is well known that small particulates can cause severe health effects.
- The EU directive 1999/30/EC limits PM_{10} concentrations in the ambient air. In many European regions these PM_{10} limits of 50 µg/m³ (daily mean value) are more often exceeded than the 35 times per year allowed.
- Domestic heating is one main PM_{10} emission source besides traffic and industry.
- Therefore, fine particulate emissions of small-scale biomass combustion plants have to be investigated, evaluated and minimised.

Intention of the project (II)

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- In order to gain more comprehensive information about fine particulate emissions from small-scale biomass combustion plants, a joint project of the
  - Austrian Bioenergy Centre, Graz,

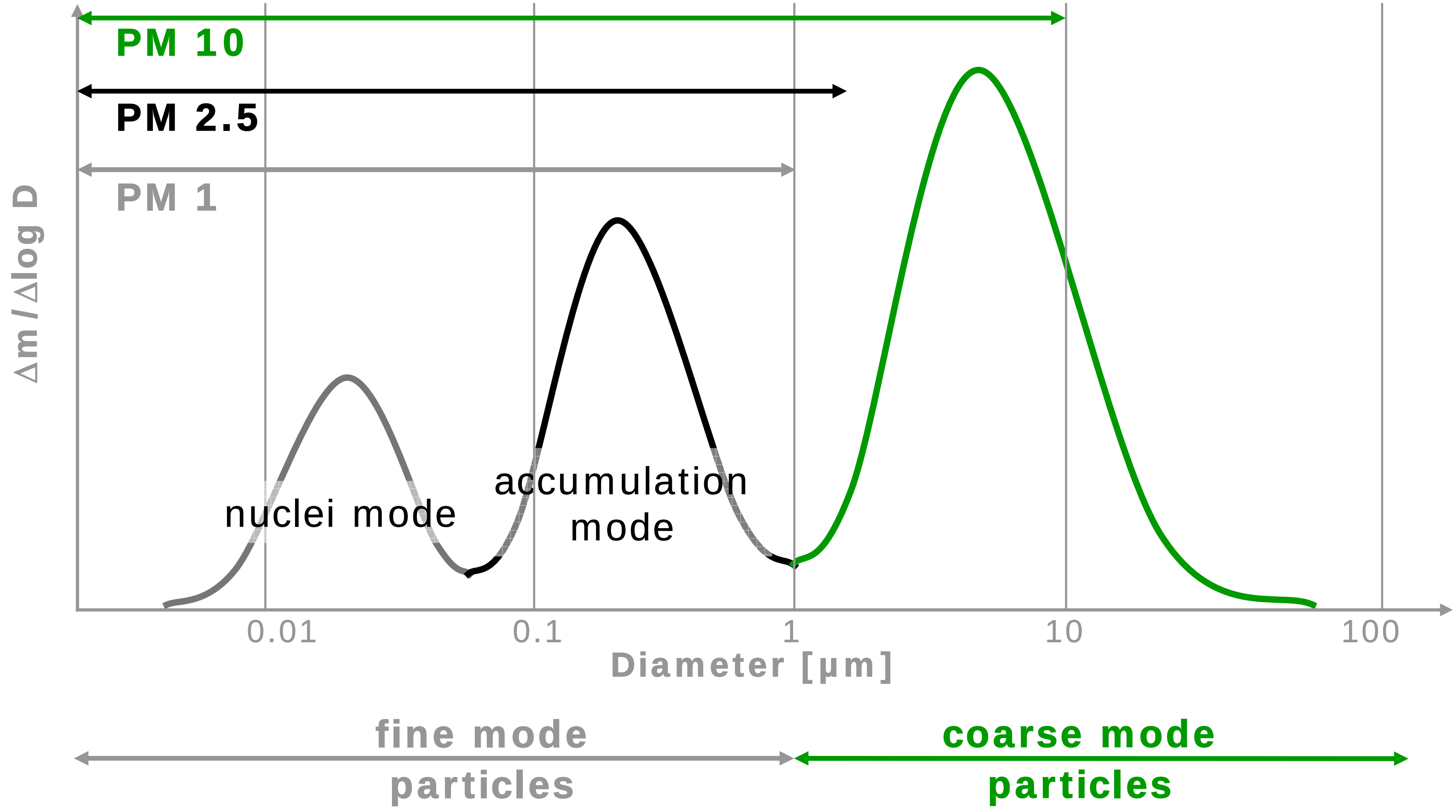
  and the

  - Institute for Resource Efficient and Sustainable Systems, Graz University of Technology

  has been started.

- The project is performed in close cooperation with 9 Austrian small-scale biomass furnace and boiler manufacturers.

Definitions – classification of atmospheric aerosols (I)



Source: Wilson and Suh, 1977

PM emissions from biomass combustion plants

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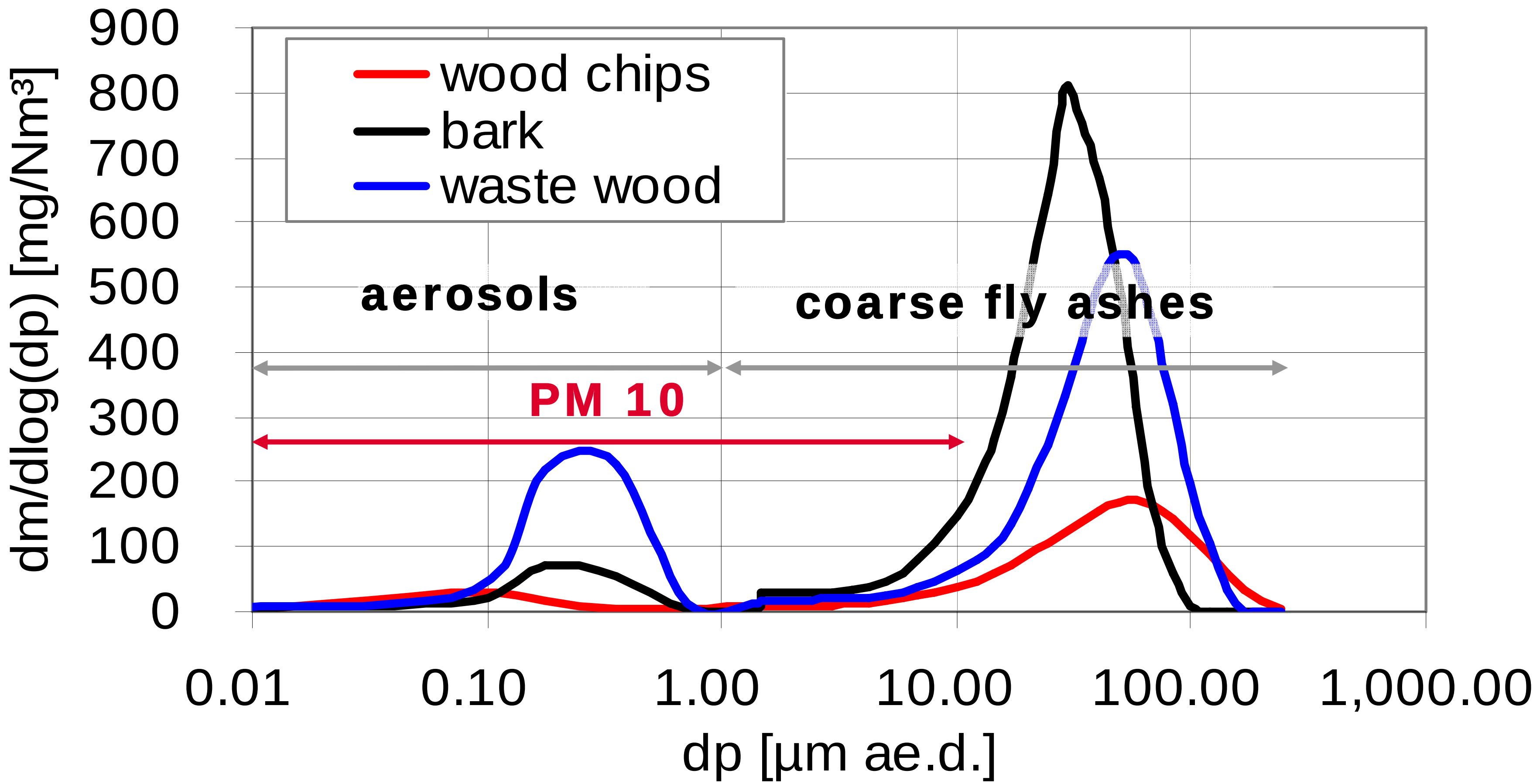
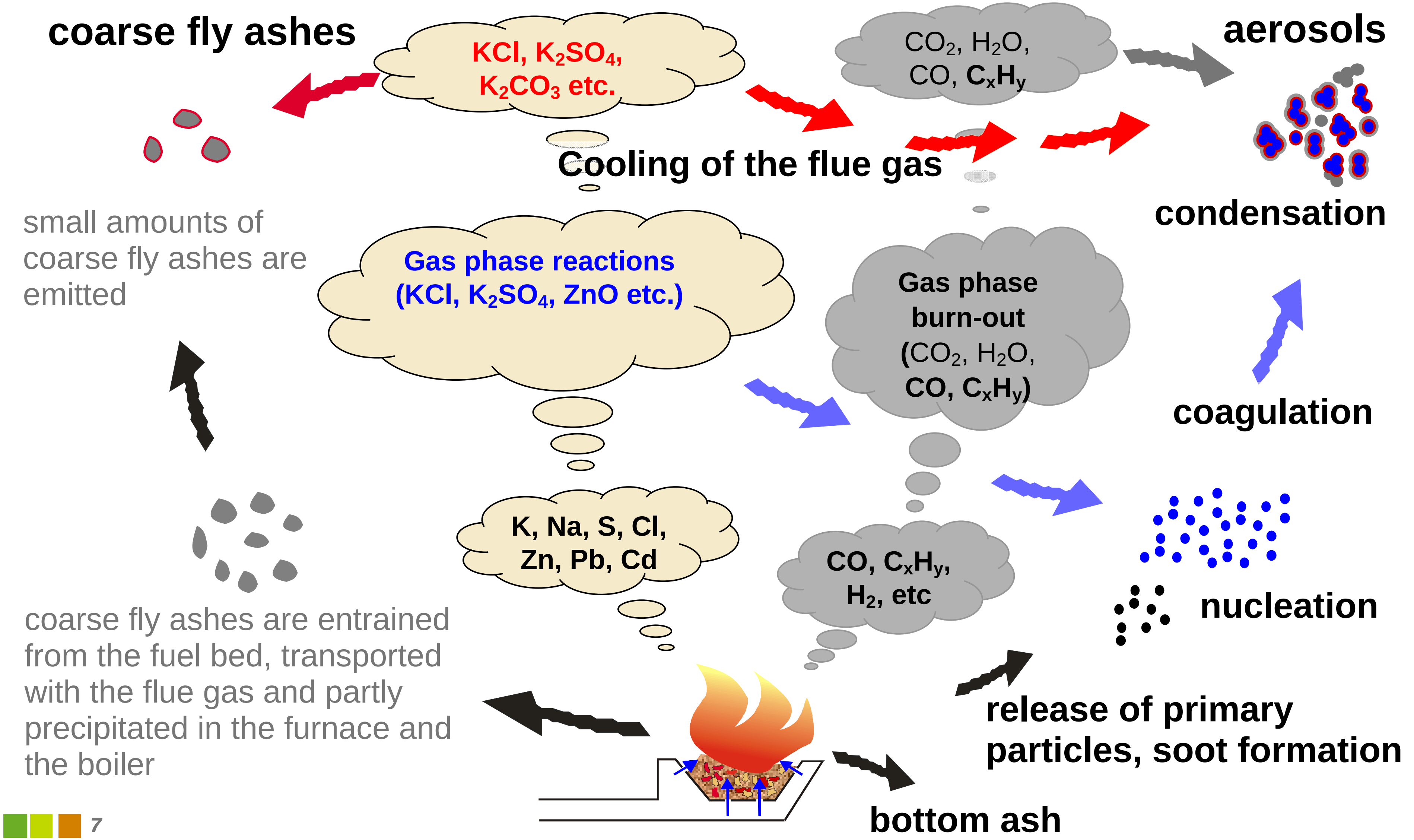
Example: Results from test runs at a grate-fired combustion plant (nominal boiler capacity: 440 kW_{th})



Aerosol formation in small-scale biomass furnaces



Methodology applied

- Test runs at small-scale pellet furnaces
  - test stand
  - field tests

- Measurement and determination of
  - total fly ash emissions
  - particle size distribution and concentration of aerosols
    - low pressure impactor (BLPI)
    - electrical low pressure impactor (ELPI)
  - flue gas composition
    (O_2, CO, TOC, NO_x)
  - operation mode of the furnace
    (furnace temperature, load, flue gas temperature)

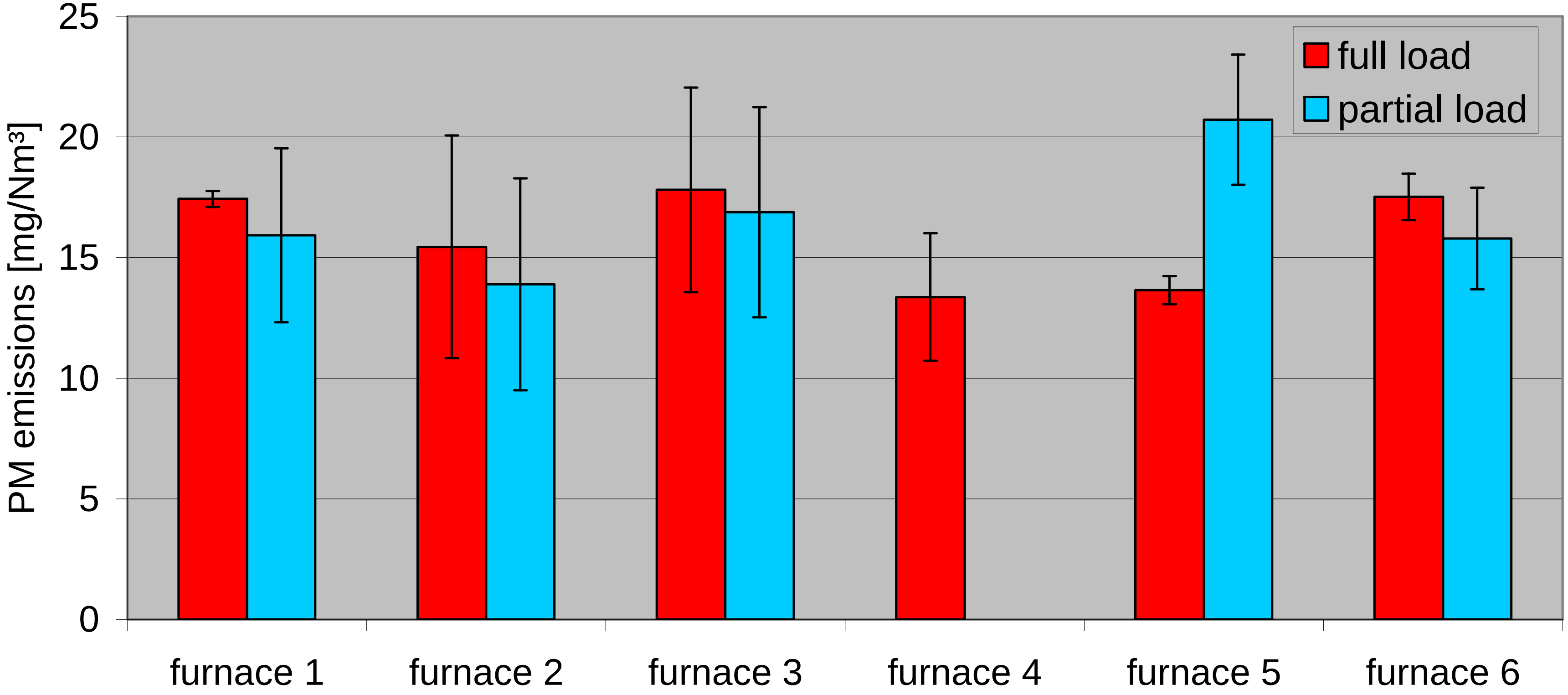
Systems tested

- state-of-the-art Austrian pellet combustion technologies
- nominal boiler capacity: 15 to 20 kW
- all furnaces were equipped with
  - automatic ignition systems
  - staged combustion
  - automatic boiler cleaning systems
  - automatic de-ashing systems
- different combustion technologies
  (underfeed stoker, overfed burner, horizontally fed burner)
- equipped with water cooled or insulated combustion chambers
- fully automated process control including λ-sensors or temperature sensors

Measurements performed

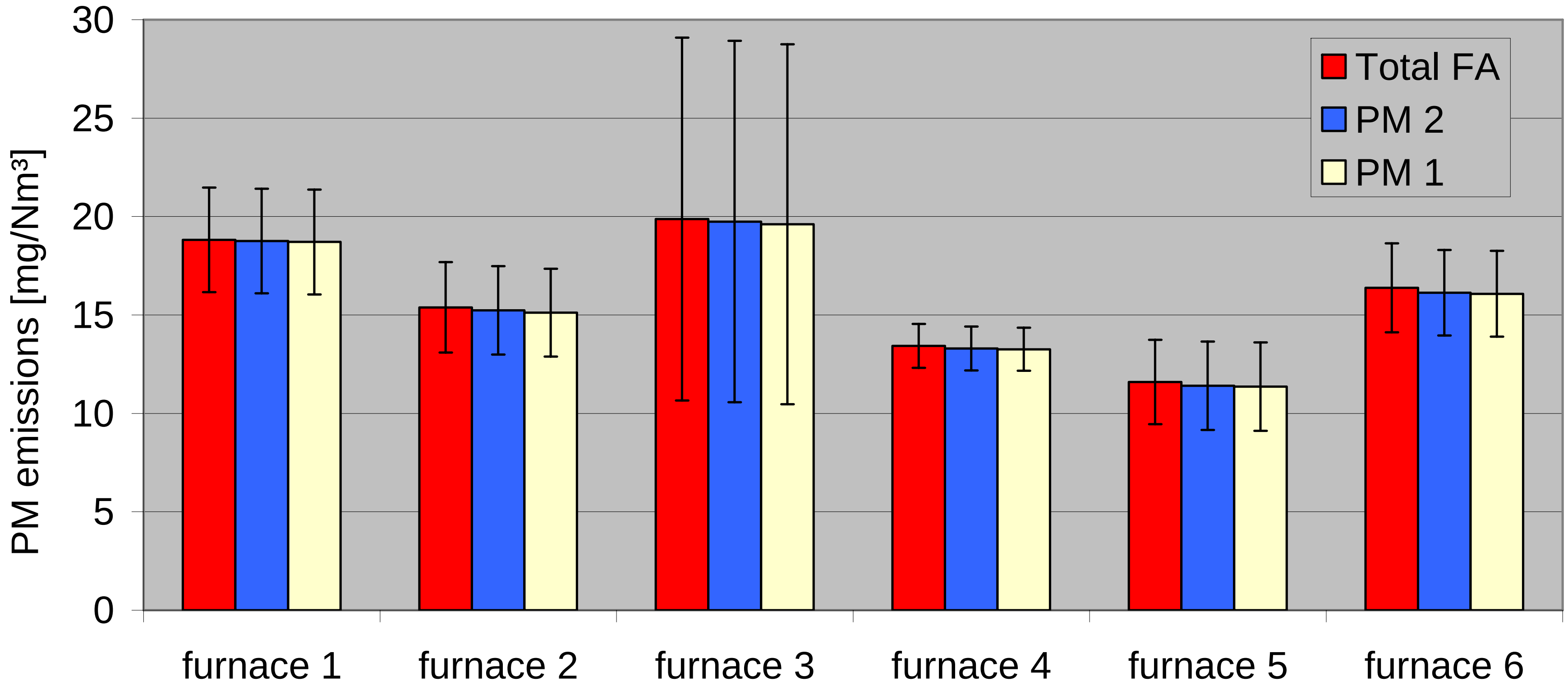
- Furnace 1: test stand measurements at different load conditions
- Furnace 2: test stand measurements at different load conditions
- Furnace 3: field measurements at full and partial load
- Furnace 4: field measurements at full load
- Furnace 5: test stand measurements at different load conditions
- Furnace 6: test stand measurements at different load conditions

Results – total fly ash emissions



Explanations: measurements performed with the total dust measurement equipment;
partial load: 50% of the nominal load
all results related to dry flue gas and 13 vol% O_2;
mean values and standard deviations of at least 3 measurements

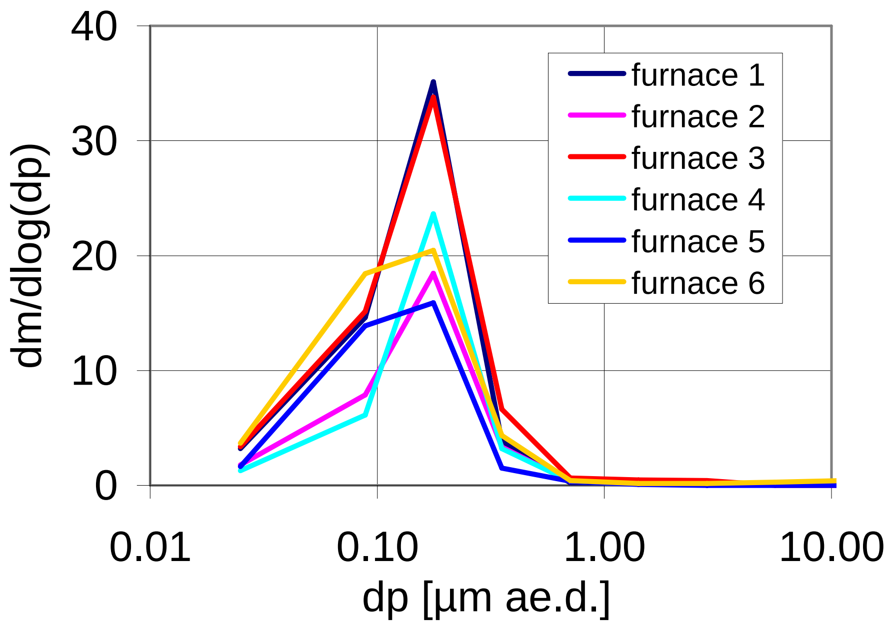
Results – total fly ash, PM_2 and PM_1 emissions at full load



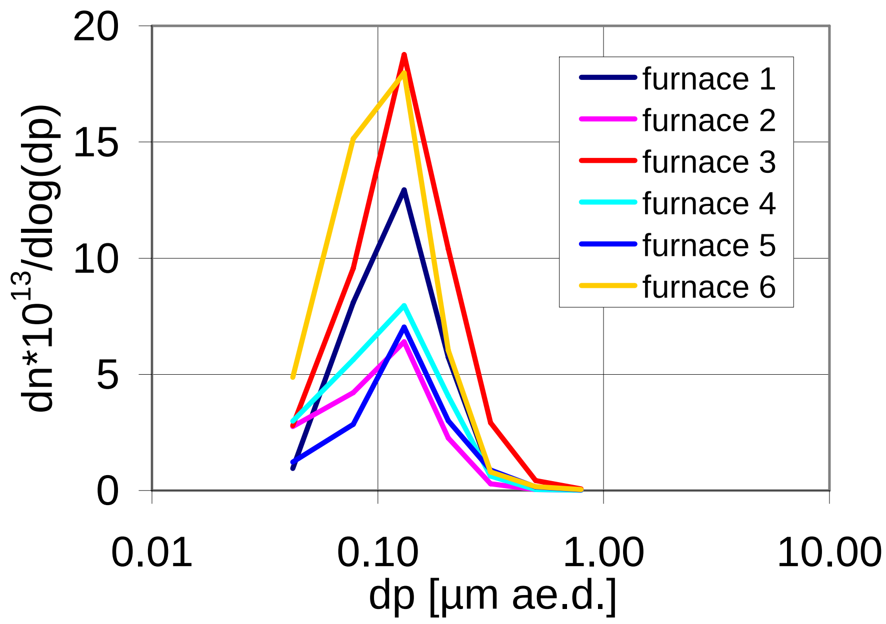
Explanations: measurements performed with the BLPI;
all results related to dry flue gas and 13 vol% O_2;
mean values and standard deviations of at least 5 measurements

Results – particle size distributions during full load operation

Particle mass size distributions

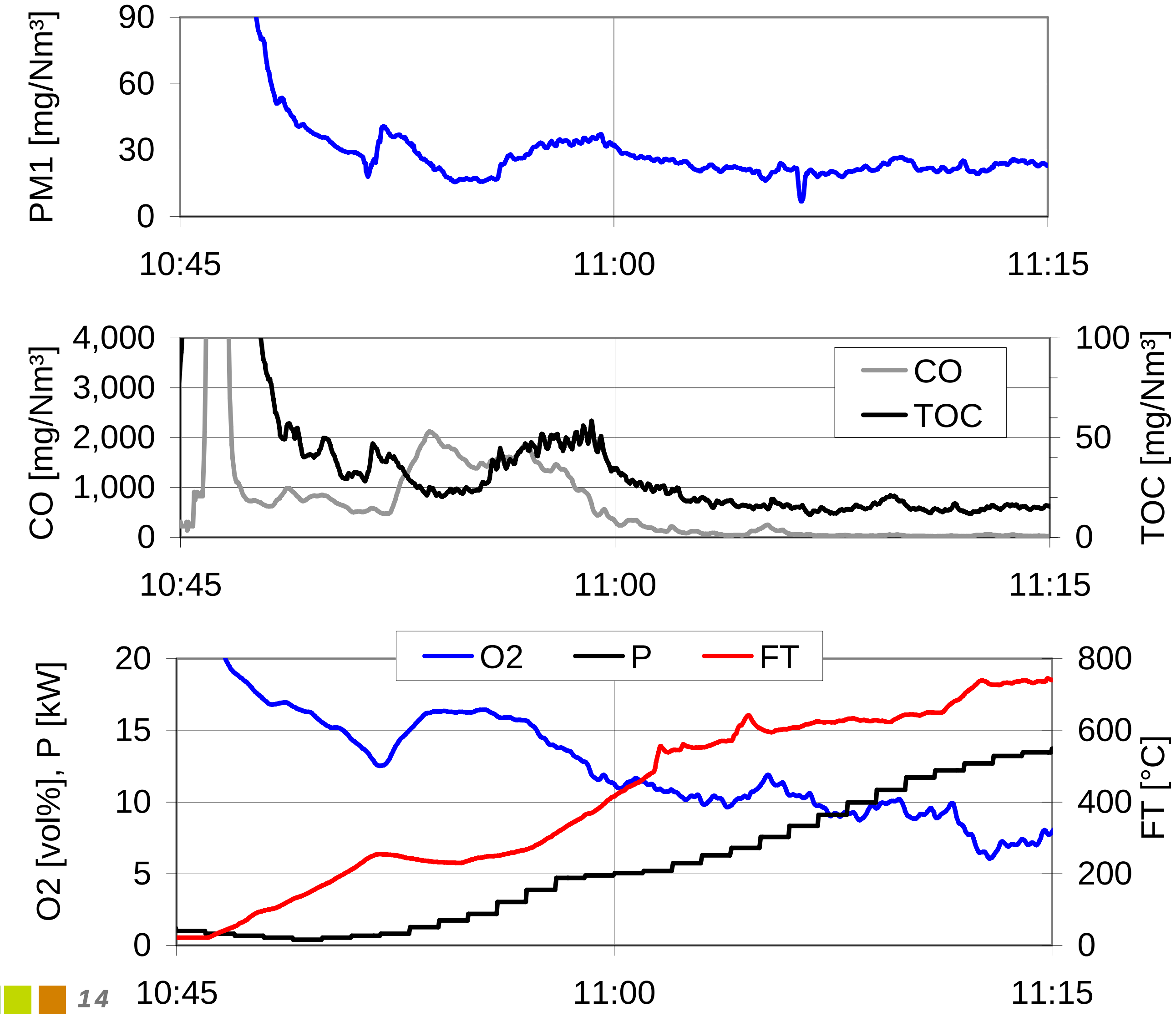


Particle number size distributions



Explanations: measurements performed with the BLPI (mass) and the ELPI (number); all results related to dry flue gas and 13 vol% O_2; ae.d.: aerodynamic particle diameter; mean values of at least 5 measurements

Results –
unstable load conditions: start up



Explanations:

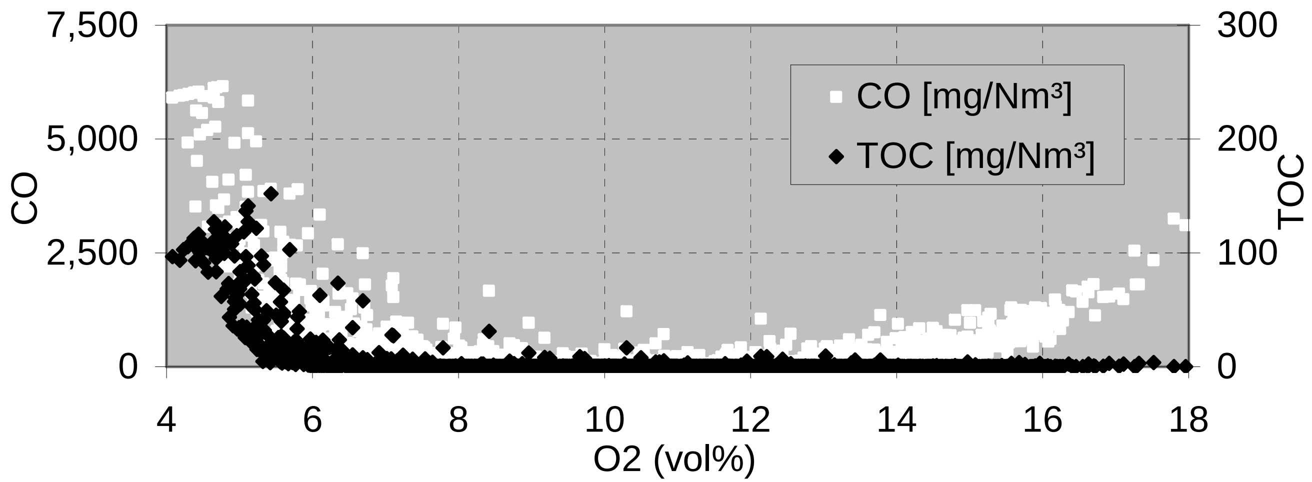
PM data from ELPI measurements;

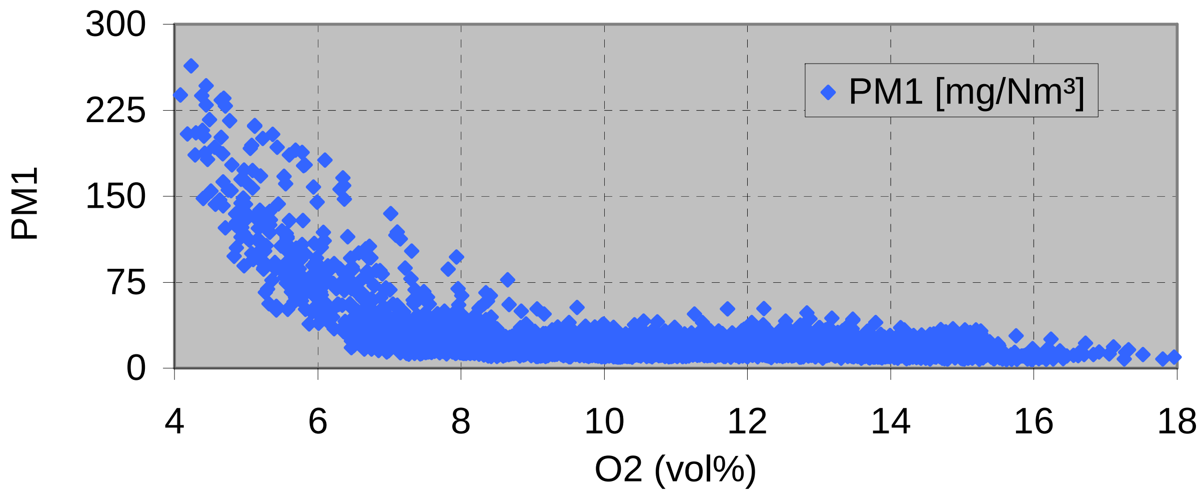
FT ... furnace temperature;

O_2 related to dry flue gas;

PM_1, CO and TOC related to dry flue gas and 13 vol% O_2;

Results – unstable load conditions: load changes





Explanations:

Results of a 5h measurement period with several load changes;

PM data from ELPI measurements;

O_2 related to dry flue gas;

PM_1, CO and TOC related to dry flue gas and 13 vol% O_2;

Results – chemical composition of the PM_1 fraction – inorganic part

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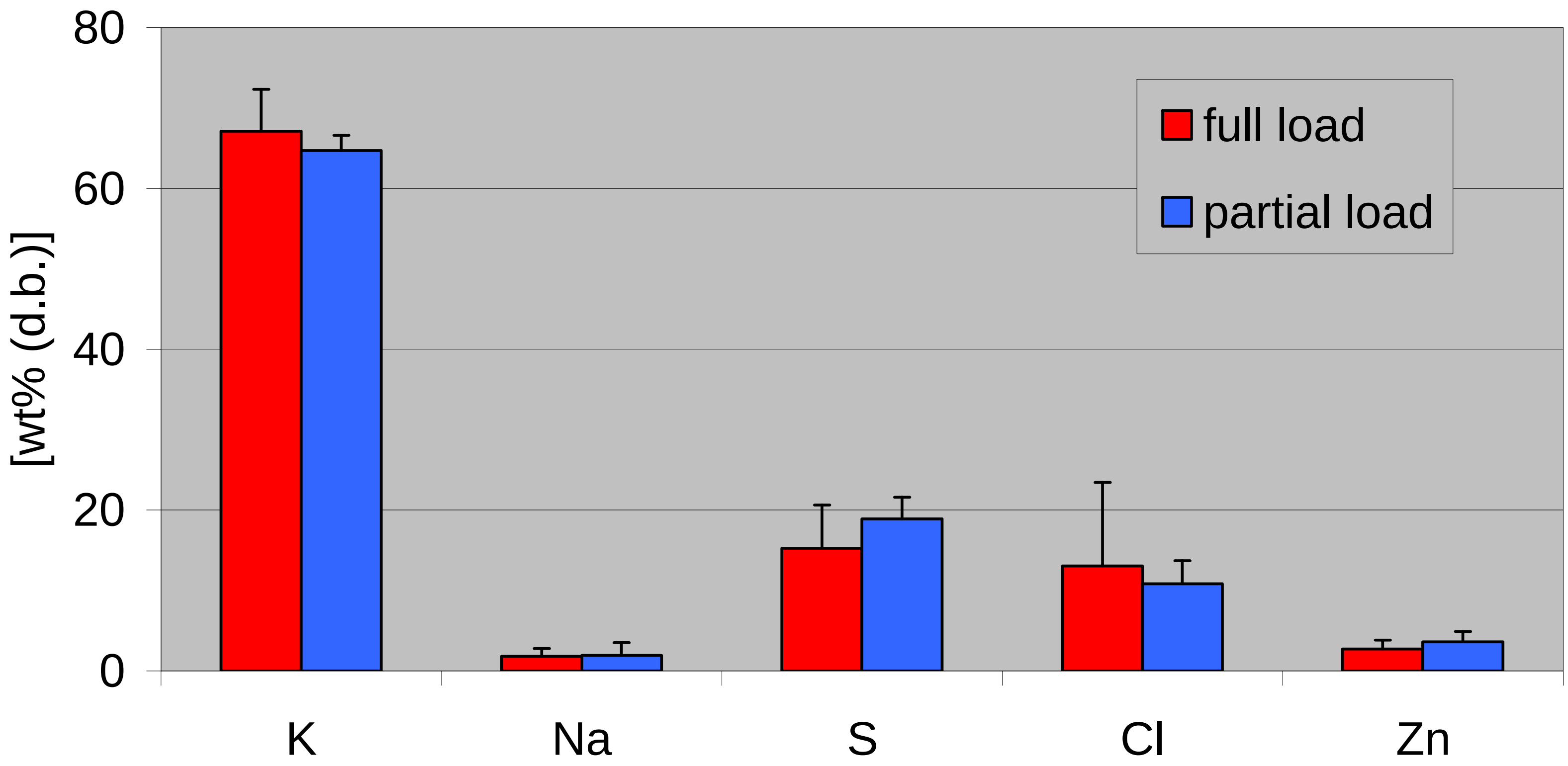

Explanations: mean values and standard deviations of at least 3 analyses per furnace investigated;
partial load: 50% of the nominal load
values normalised to 100% without O and C

Results – structure and chemical composition of fine particulates

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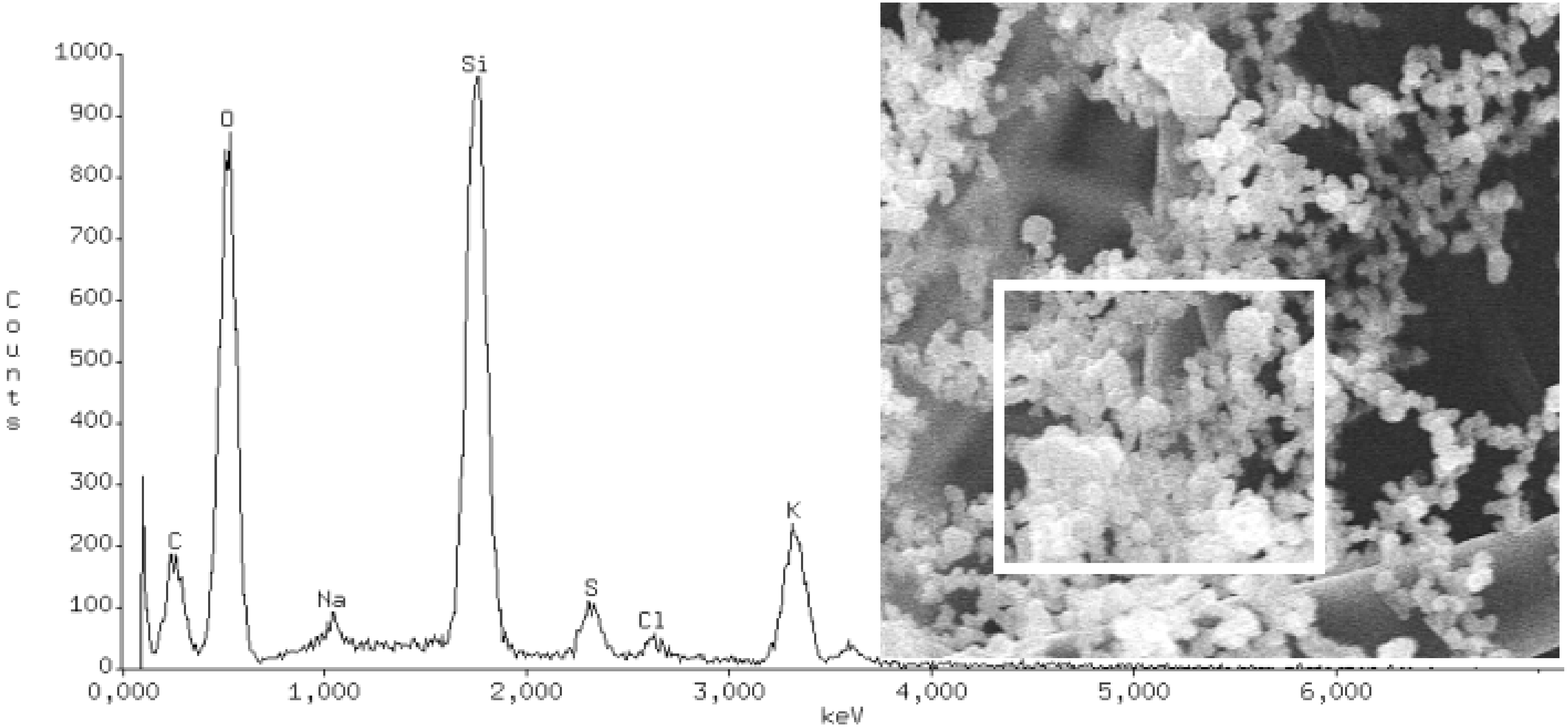

Explanations: EDX-scan from area marked in the SEM-image;
particle sampling during full load operation with a 3-stage impactor;
Si originates from the filter material; picture width: 2 µm

Conclusions (I)

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- Average total dust emissions during stable full and partial load operation:
  <20 mg/Nm³ (dry flue gas and 13 vol% O_2) respectively
  <13.3 mg/MJ_{NCV}

- The average number concentration of small particulate emissions (particles <1µm) is in the range of 10^{13} particles/Nm³

- More than 95% of the total dust emissions are PM1

- Compared with literature data available for older pellet furnace technologies (emissions up to 100 mg/Nm³), a considerable reduction of particulate emissions due to improved combustion conditions and therefore a considerable reduction of organic aerosols has been observed.

Conclusions (II)

- No significant differences concerning the particulate emissions with respect to
  - full load and partial load operation
  - different furnace technologies applied
  - test runs at the test stand and field measurements
- During start-up as well as during load changes (change from partial to full load), operation conditions with insufficient gas phase burnout and therefore, with increased particle formation occur.

Conclusions (III)

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- At stable operation conditions and sufficient gas phase burnout:
  - aerosols formed mainly consist of K, Na, S, Cl as well as Zn and show only minor concentrations of organic C.
  - concerning these operation conditions, mainly the chemical composition of the fuel influences the mass of aerosols formed.
- Consequently, the combustion of fuels with low concentrations of aerosol forming species (e.g. clean wood pellets) causes considerably lower particulate emissions than the combustion of alkaline, S and Cl rich fuels (e.g.: herbaceous fuels).

Conclusions (IV)

➢ During unstable operation conditions causing insufficient gas phase burnout:

- fine particle emissions significantly increase for short operation periods.
- the concentration of the organic carbon content in the fine particulates significantly increases.

➢ Consequently, advanced process control technologies and appropriate furnace designs should be developed and applied in order to keep operation periods at insufficient gas phase burnout conditions as short as possible.

Recommendations

- Two relevant primary measures for particulate emission reduction in small-scale pellet boilers can therefore be recommended.
  - Utilisation of fuels with low concentrations of inorganic aerosol forming species (e.g. softwood pellets).
  - Application of advanced furnace designs and process control systems.

- The substitution of old wood furnaces by state-of-the-art pellet combustion technologies should be enforced and maybe even subsidised by the state respectively regional governments.

- For a further reduction of particulate emissions below the range of about 15 mg/Nm^3 secondary measures (e.g. small-scale ESP systems or scrubbers) are needed which are currently under development but not yet sufficiently tested.

ACKNOWLEDGEMENTS

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