BIO-AEROSOLS

Aerosols in fixed-bed biomass combustion

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ENLARGED PERSPECTIVES

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BIO-AEROSOLS

Aerosols in fixed-bed biomass combustion

formation, growth, chemical composition, deposition, precipitation and separation from flue gas

1st of March 2000 to 28th of February 2003

The consortium

PROJECT CO-ORDINATOR:

- Graz University of Technology (A)
  Institute of Chemical Engineering Fundamentals and Plant Engineering

PARTNERS:

- Technical University of Denmark
  Department of Chemical Engineering (DK)
- Abo Akademi University
  Department of Chemical Engineering (Fi)
- University of Technology
  Faculty of Mechanical Engineering (NL)
- ERC Emissions-Reduzierungs-Concepte GmbH (G)
- Standardkessel Lentjes GmbH (G)
- MAWERA Feuerungsanlagen GmbH (A)

Objectives of the project

- Investigation of typical characteristics of aerosols and fly ashes as well as of boiler tube deposits formed in fixed-bed biomass combustion plants using woody biofuels
- Determination of parameters influencing aerosol and fly ash formation
- Modelling of aerosol formation and behaviour
- Development and test of additives to influence formation, behaviour and chemical composition of aerosols and deposits
- Aerosol and fly ash precipitation in small-, medium- and large-scale biomass combustion units
- Environmental and health aspects concerning aerosol emissions from biomass combustion

Methodology (I)

- **Performance of test runs at fixed-bed biomass combustion units at different operation modes including the determination of**
  - concentration and particle size distribution of aerosols and fly ashes
  - chemical composition of aerosols and fly ashes
  - deposit formation in the boiler section
  - evaluation of the influence of additive injection on aerosol and deposit formation
- **Mathematical modelling of**
  - aerosol and fly ash formation and growth
  - deposit formation
- **Detailed study concerning ecological and health risks of aerosol emissions from biomass combustion**
  - performance of in-vivo and in-vitro studies with particulates sampled during the test runs

Methodology (II)

Combustion plants used and fuels considered

- **Pilot-scale combustion unit**
  - **Technology:** horizontally moving grate
    fire tube hot water boiler (440 kW_{th})
  - **Fuels:** wood chips (beech, spruce)
    bark
    fibreboards
    waste wood
- **Large-scale CHP unit**
  - **Technology:** moving grate
    steam boiler (40 MW_{el})
  - **Fuels:** different assortments of waste wood

Results – data gained from the test runs (I)

Comprehensive data sets concerning

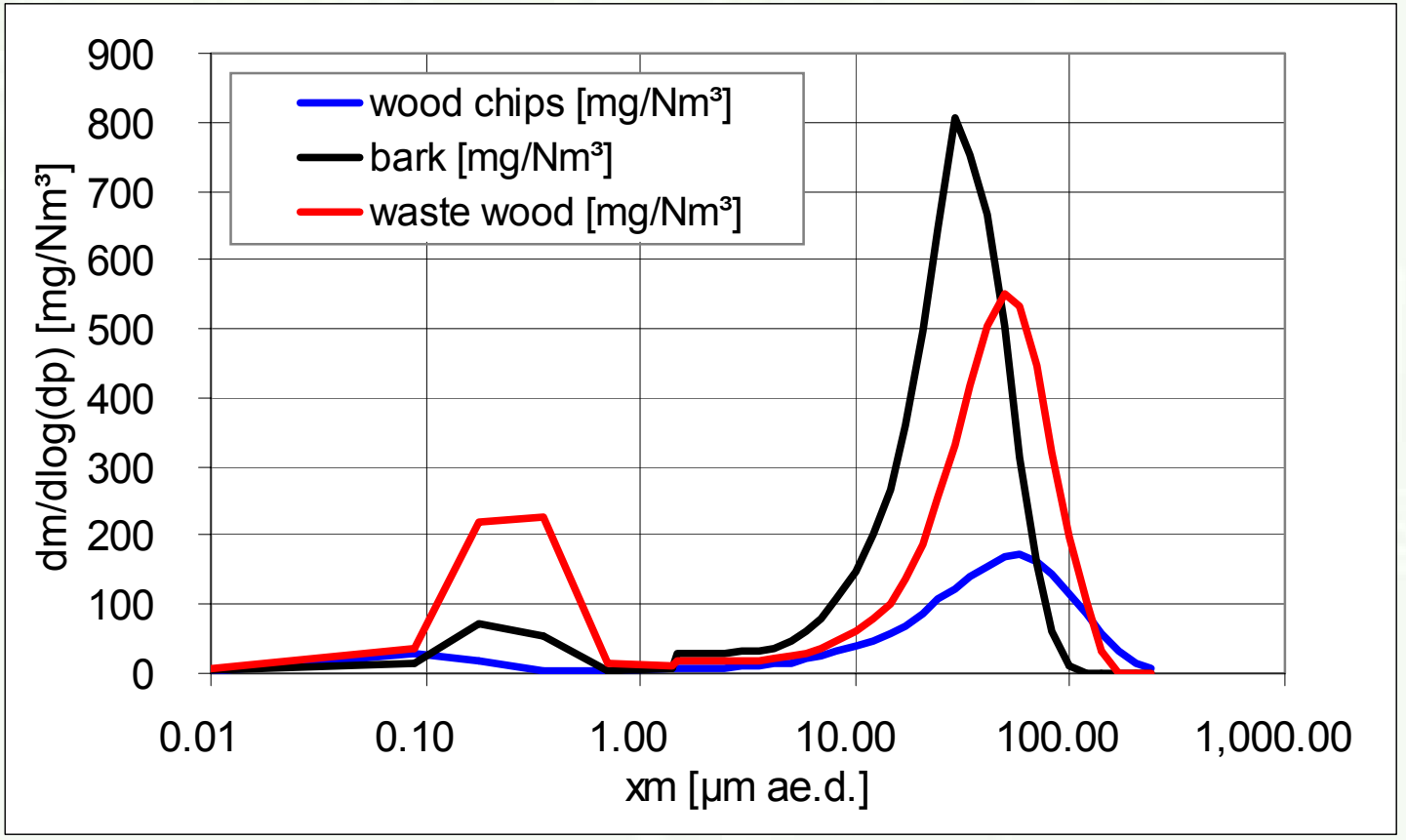
- **Characterisation of aerosols and fly ashes at the boiler outlet for different woody biomass fuels**
  - concentration in the flue gas
  - particles size distribution
  - shape of the particles (by SEM-analyses)
  - chemical composition of different particle fractions (by SEM/EDX and wet chemical analyses)
- **Characterisation of ash deposits formed**
  - rate of deposit build up (RBU, by deposit probe measurements)
  - structure of the deposits (SEM-analyses of deposit probe samples)
  - chemical composition of deposits (by SEM/EDX-analyses of deposit probe samples)

Results – data gained from the test runs (II)

- **Behaviour of ash and aerosol forming elements during combustion**
  - **Performance of mass and element balancing test runs over the pilot-scale combustion unit**
  - **Evaluation of the element balances with special respect to the release behaviour of aerosol forming elements from the fuel**
- **Influences of injection of an additive into the hot furnace on aerosol formation, deposit build-up and chemical composition of deposits formed**
- **Data concerning the health effects of aerosol emissions gained from in-vivo and in-vitro studies**

Conclusions – aerosol and fly ash formation

Typical particle size distributions of aerosols and fly ashes formed during fixed-bed combustion of woody biofuels



Conclusions – aerosol and fly ash formation

- **Aerosol formation is mainly influenced by the chemical composition of the fuel (main constituents: K, Na, S, Cl, Zn, Pb)**
- **The aerosol concentration in the flue gas increases with increasing concentrations of K, Na, Zn and Pb in the fuel.**
  - **about 20 mg/Nm³ (for spruce, low alkaline / heavy metal content)**
  - **up to 100 mg/Nm³ (for beech and bark, higher alkaline / medium heavy metal content)**
  - **up to 400 mg/Nm³ (waste wood, high alkaline / heavy metal content)**
- **Coarse fly ash formation is mainly influenced by the**
  - **ash content of the fuel**
  - **load of the combustion unit**
  - **operation mode (combustion air distribution over the fuel bed)**
  - **combustion technology (fixed-bed, fluidised bed, etc.)**
- **Coarse fly ash emissions in the range between 100 mg/Nm³ up to more than 1,000 mg/Nm³ were determined**

Conclusions – aerosol and fly ash formation

Modelling of aerosol and fly ash formation

- **In general, a rough estimation of the mass and particle size distribution of aerosols based on the knowledge about the chemical composition of the fuel and the time-temperature profile of the combustion unit was possible.**

- **Weak points**
  - **The release of aerosol forming species from the fuel can, at the moment, not be modelled and measured data are rare.**
  - **Relevant thermodynamic data for heavy metals (especially for Zn, Pb) are missing.**
  - **Effects such as surface condensation and thermophoresis on boiler tubes play an important role concerning the final concentration of aerosols in the flue gas and have to be estimated correctly.**

Conclusions – aerosol precipitation

- Aerosol and fly ash precipitation in medium and large-scale biomass combustion units
  - Highly efficient technologies are available
    - ESP
    - baghouse filters
- Aerosol and fly ash precipitation in small-scale biomass combustion units
  - Usually cyclones and multi-cyclones are applied
  - With these technologies no aerosol precipitation is possible
  - Highly efficient aerosol precipitators are economically not affordable for small-scale units
  - Low-cost aerosol precipitators for small-scale combustion units are not yet developed

Conclusions – deposit formation

- The RBU is partly coupled to the fuel used. Therefore, fuel characterisation is important for the prediction of deposit formation.
- Different types of waste wood gave rise to higher RBUs than measured for wood and bark. The reasons were the higher concentration levels of Na, Zn, Pb, S and Cl in waste wood.
- Compounds of Na, Zn, Pb, S and Cl lower the melting point of the ashes, and molten phases in deposits will promote the formation of hard deposits which are difficult to remove.
- During test runs with additive injection a slight decrease of the RBU and an increase of the porosity of the deposits was recognised.

Conclusions – health effects

- In general, fine particles can be inhaled and therefore can cause respiratory problems such as asthma, chronic obstructive pulmonary disease, pneumonia and lung cancer.
- With decreasing particle diameter these problems increase due to deeper inhalation and the higher specific surface of the particles.
- In-vivo and in-vitro studies indicated, that the toxicity of particulate emissions from biomass combustion is in about the same range as the one of particulate emissions from coal combustion. However, to gain higher statistical confidence levels, additional investigations have to be performed.
- Almost no correlations between the characteristics of aerosols from the combustion of different biomass fuels (size and chemical composition) and health effects were detected. Consequently, additional comprehensive studies are needed to identify the most important parameters governing the health risks of aerosol emissions.

Further research needed

- From BIO-AEROSOLS a huge amount of data and comprehensive experiences concerning aerosols, fly ashes and deposits formed during fixed-bed combustion of woody biofuels has been gained.
- BIO-AEROSOLS increased the knowledge on this topic significantly but also showed, that future research in this field is necessary and should focus on:
  - Investigations concerning the release of aerosol forming species from the fuel during combustion.
  - Improved modelling of aerosol formation and of deposit formation based on improved release data and thermodynamic data as well as the implementation of Computational Fluid Dynamics (CFD)
  - Development of efficient but low-cost aerosol precipitation technologies for small-scale biomass combustion units
  - Comprehensive studies concerning the health effects of aerosol and fly ash emissions from biomass combustion plants