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Influence of combustion conditions on the genotoxic potential of fine particle emissions from small-scale wood combustion

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Content

- Introduction and objectives
- Methodology
  - Biomass combustion systems investigated
  - Operation of biomass combustion systems
  - Experimental set-up
- Results
- Conclusions and Recommendations

Introduction

- **Present state of knowledge**
  - **Differences** exist regarding the particulate matter (PM) emissions of old and modern systems as well as automatically and not automatically controlled biomass combustion systems
  - This concerns the magnitudes, particle size distributions as well as the **chemical compositions** of the particles

- **It is assumed that**
  - the **chemical composition** of PM (organic compounds and soot) significantly influences the health risks they cause
  - PM emissions from **incomplete** combustion seem to be more harmful than those from complete combustion

Objectives

- **Characterisation of PM emissions from different typical old and modern residential biomass combustion systems by**
  - **concentration in the flue gas**
  - **chemical composition**
  - **toxicological in-vitro studies**
- **Evaluation of the dependencies between combustion technology respectively burnout quality and the chemical properties of the PM emissions**
- **Investigation of the whole causative chain and identification of correlations between**
  - **the combustion systems performance in terms of burnout**
  - **the chemical characteristics of PM_1 emissions and**
  - **the toxicological potential associated to these emissions**

Methodology – general information

- **Performance of test runs with a broad variety of different residential biomass combustion systems over typical whole day operation cycles**
  - **Recording of relevant operation data**
  - **Gaseous and PM emission measurements**
  - **PM_1 sampling for subsequent**
    - chemical characterisation
    - toxicological in-vitro studies
- **2 respectively 6 (tiled stove) test runs with the biomass combustion systems investigated were performed**

Methodology – biomass combustion systems investigated

- Representative cross section of residential heating technologies presently applied in Europe

- Small-scale biomass combustion systems tested
  - modern pellet boiler (21 kW)
  - modern wood chip boiler (30 kW)
  - modern logwood boiler (30 kW)
  - old logwood boiler (15 kW)
  - modern logwood fired stove (6 kW)
  - old logwood fired stove (6.5 kW)
  - modern logwood fired tiled stove (4.2 kW)

Methodology – operation of biomass combustion systems

- **Simulation of typical whole day operation cycles**
  - **automatically fed and automatically controlled systems**
    - start-up and shut down procedures
    - load changes
    - stable full and partial load operation
  - **manually fed and automatically controlled systems**
    - ignition phase, main combustion and burnout phase considered
  - **manually fed natural draught system**
    - all operation phases including ignition batches considered

Methodology – experimental set-up (I)

- Test stand setup is based on recommendations for particle sampling for toxicological tests, worked out within the ERA-NET Bioenergy project BIOMASS-PM and generally follows the setup described in EN 13240
- Flue gas was diluted with pre-cleaned particle free pressurised air before the particle sampling in order to convert condensable organic species into particles
- Diluted flue gas: temperature below 40°C
- All measurements as well as PM_1 emission sampling took place over the whole testing cycle

Methodology – experimental set-up (II)

Particle measurement and sampling

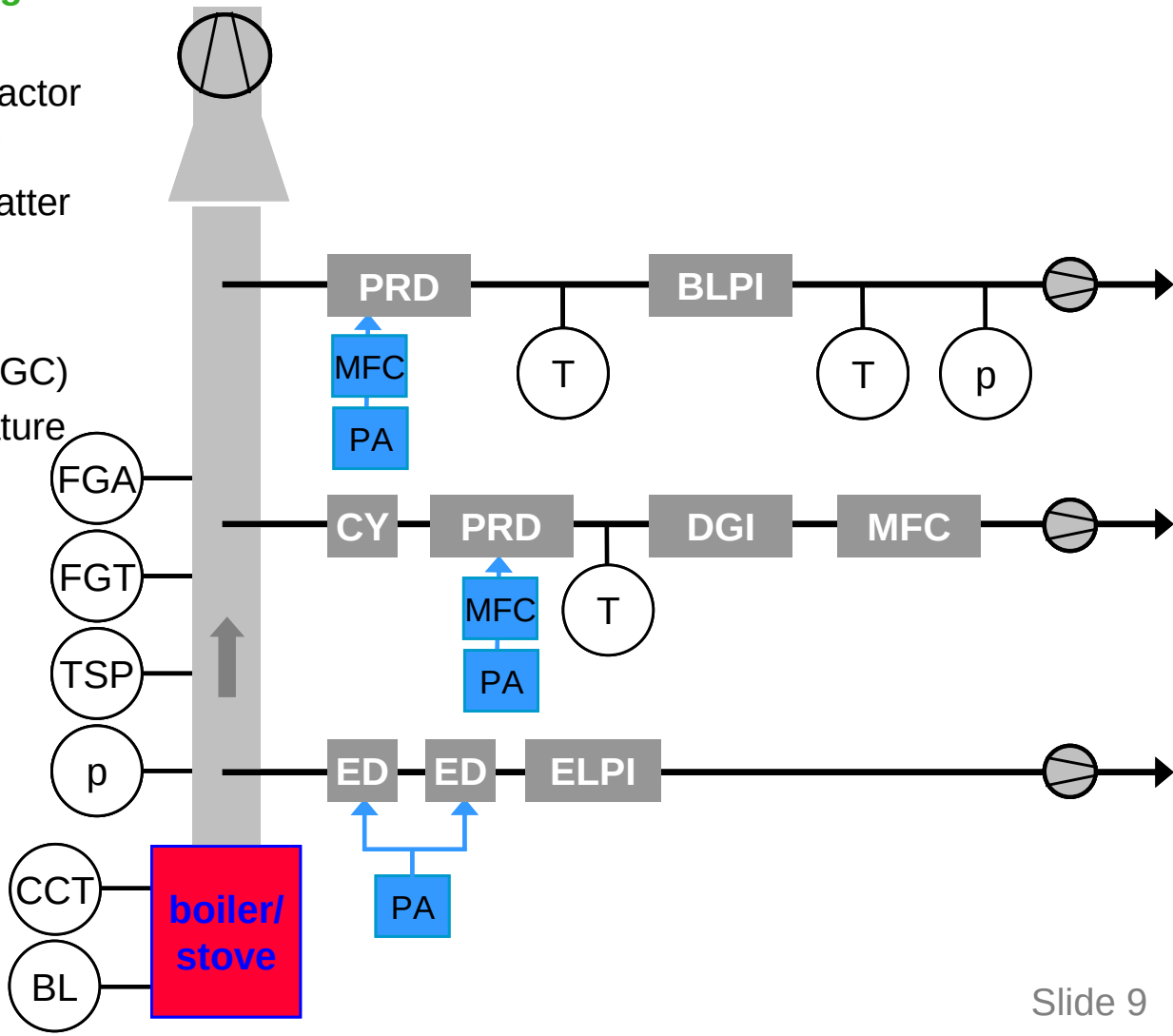
DGI Dekati gravimetric impactor
BLPI Berner-type low-pressure impactor
ELPI electric low pressure impactor
TSP total suspended particulate matter according to VDI 2066

Plant operation parameters

FGA flue gas analysers (O_2, CO, OGC)
CCT combustion chamber temperature
FGT flue gas temperature
BL boiler load

Flue gas dilution systems

PRD porous tube diluter
ED ejector diluter
CY PM_{10} cyclone
PA pressurised air
MFC mass flow controller
p pressure measurements
T temperature measurements

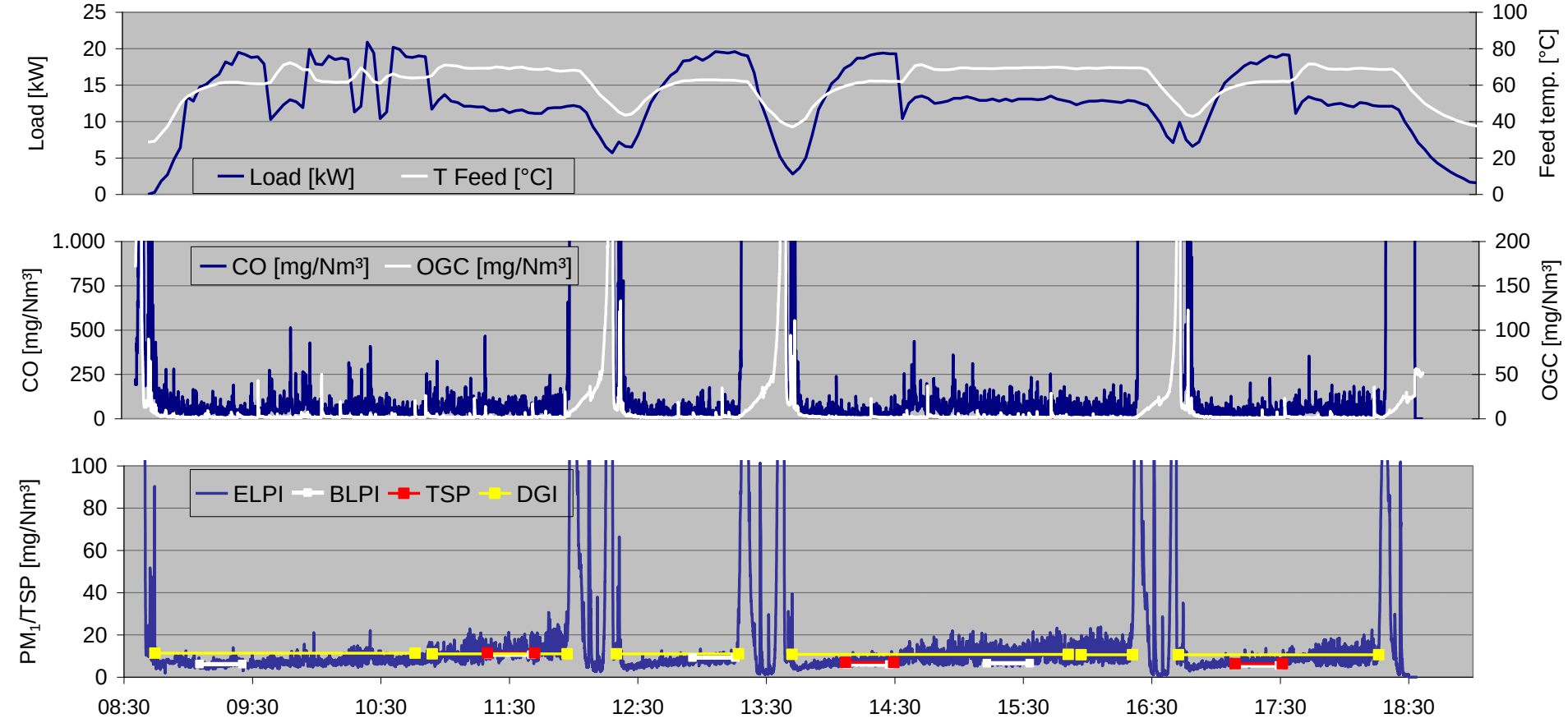


Methodology – chemical analyses of PM and toxicological tests

- **Determination of the chemical composition of selected aerosol samples regarding**
  - **organic carbon (OC), elemental carbon (EC)**
  - **inorganic components**

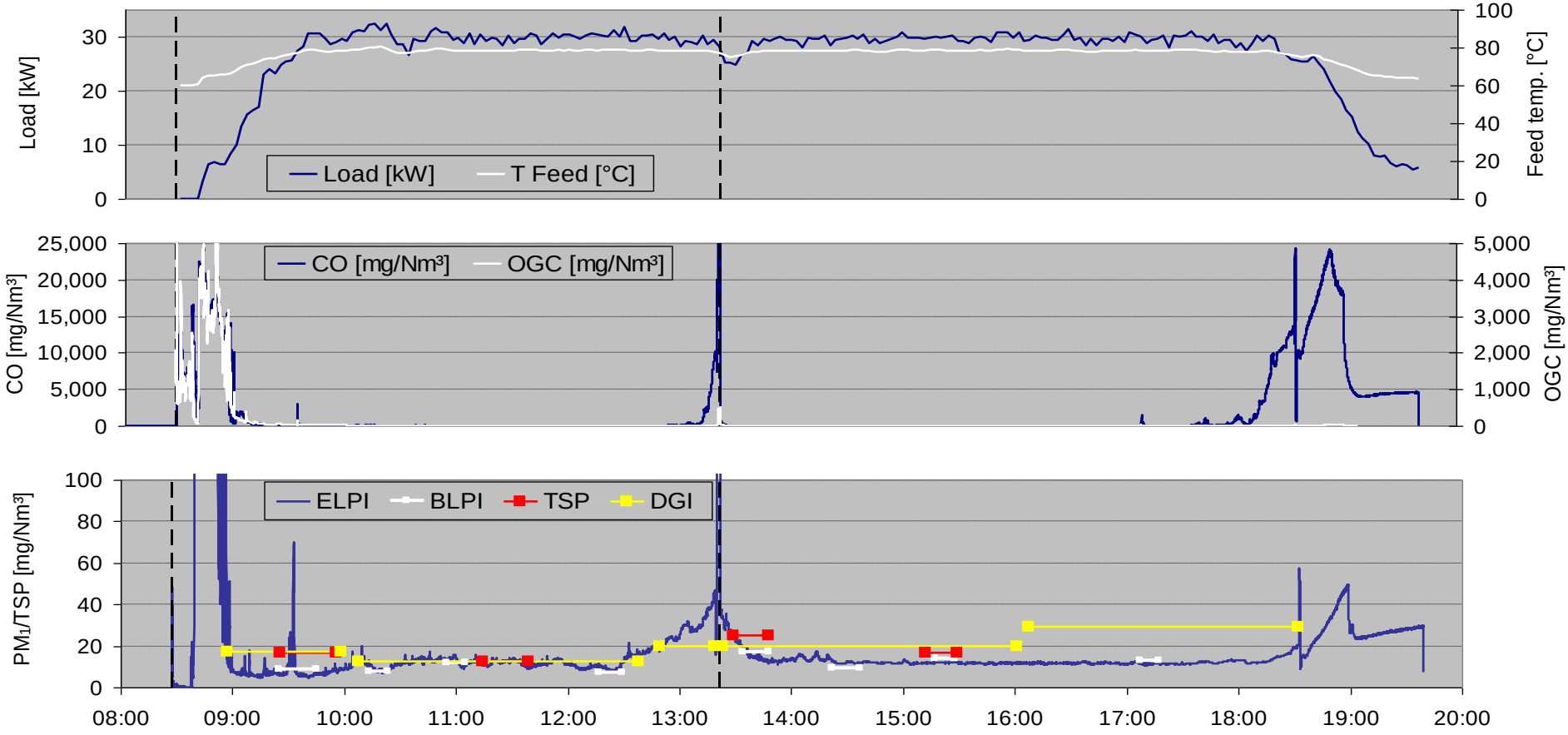
- **Toxicological tests**
  - **Mouse RAW264.7 macrophage cell lines were separately exposed to four doses (15, 50, 150 and 300 µg/ml) of each PM_1 sample for 24 hours**
  - **The specific aims of the toxicological in-vitro tests were**
    - to investigate cell death
    - to study the inflammatory responses caused by PM
    - to assess the PM induced genotoxicity as measures for possible health effects caused by these emissions

Results – emission profiles – modern pellet boiler



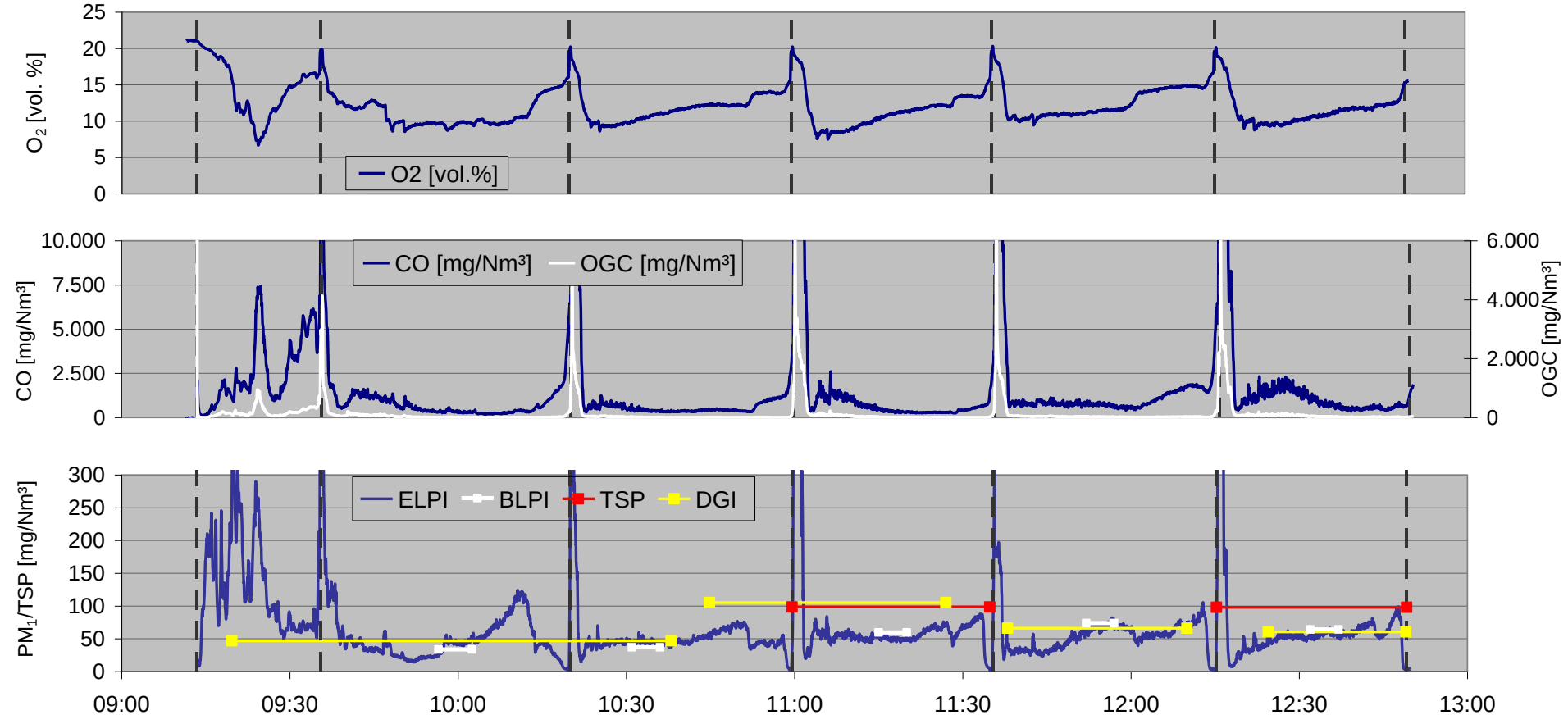
Explanations: fuel: pellets according to ÖNORM M 7135; data related to dry flue gas and 13 vol% O_2; T Feed … feed temperature; load … boiler load; the BLPI, TSP and DGI lines indicate the measured PM concentration over the respective sampling period

Results – emission profiles – modern logwood boiler



Explanations: fuel: logwood according to ÖNORM M 7132; data related to dry flue gas and 13 vol% O_2; T Feed … feed temperature; load … boiler load; the BLPI, TSP and DGI lines indicate the measured PM concentration over the respective sampling period

Results – emission profiles – modern logwood fired stove

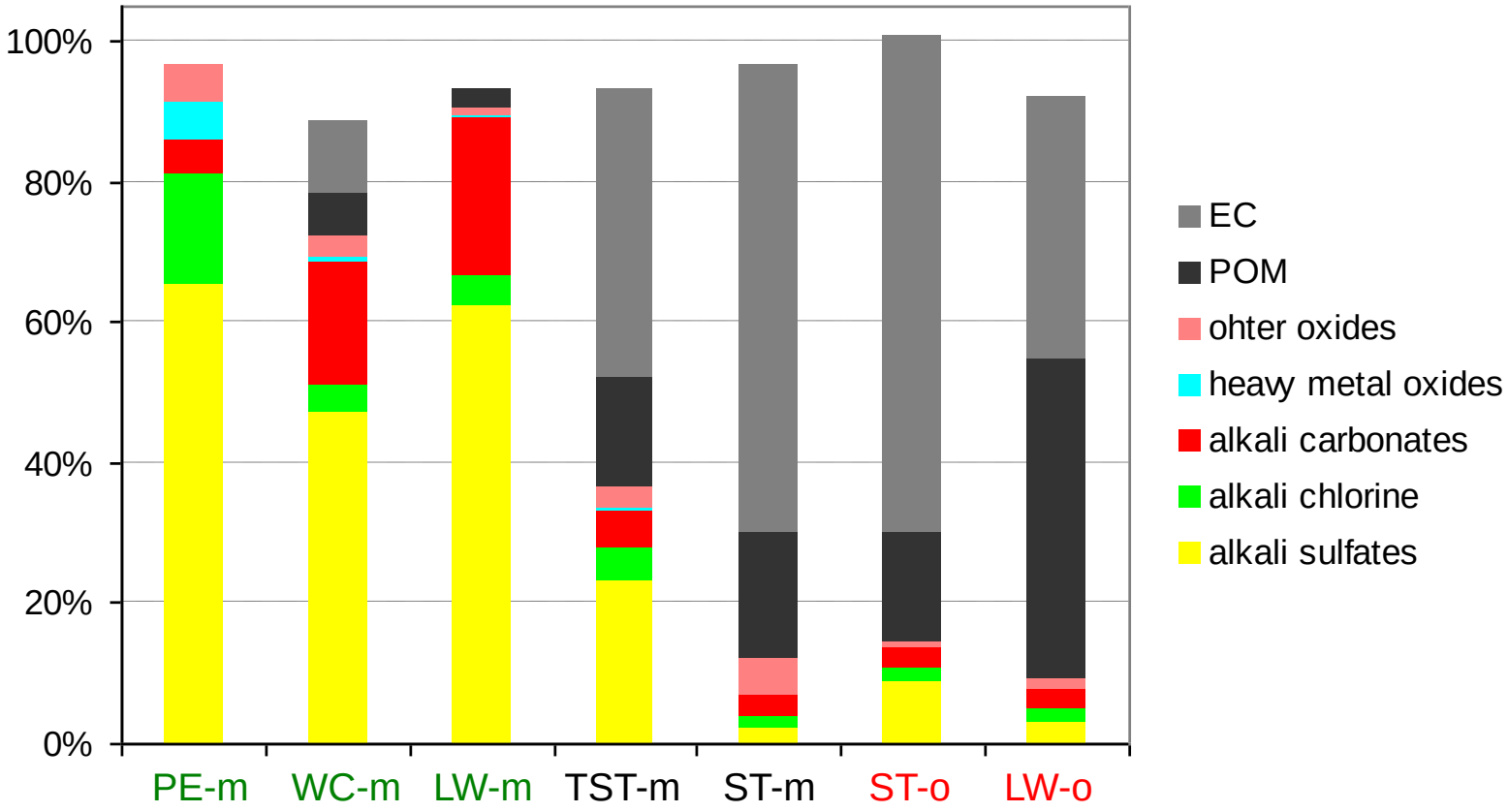


Explanations: fuel: logwood according to ÖNORM M 7132; data related to dry flue gas and 13 vol% O_2; the BLPI, TSP and DGI lines indicate the measured PM concentration over the respective sampling period

Results – average gaseous and particulate emissions over the test runs performed

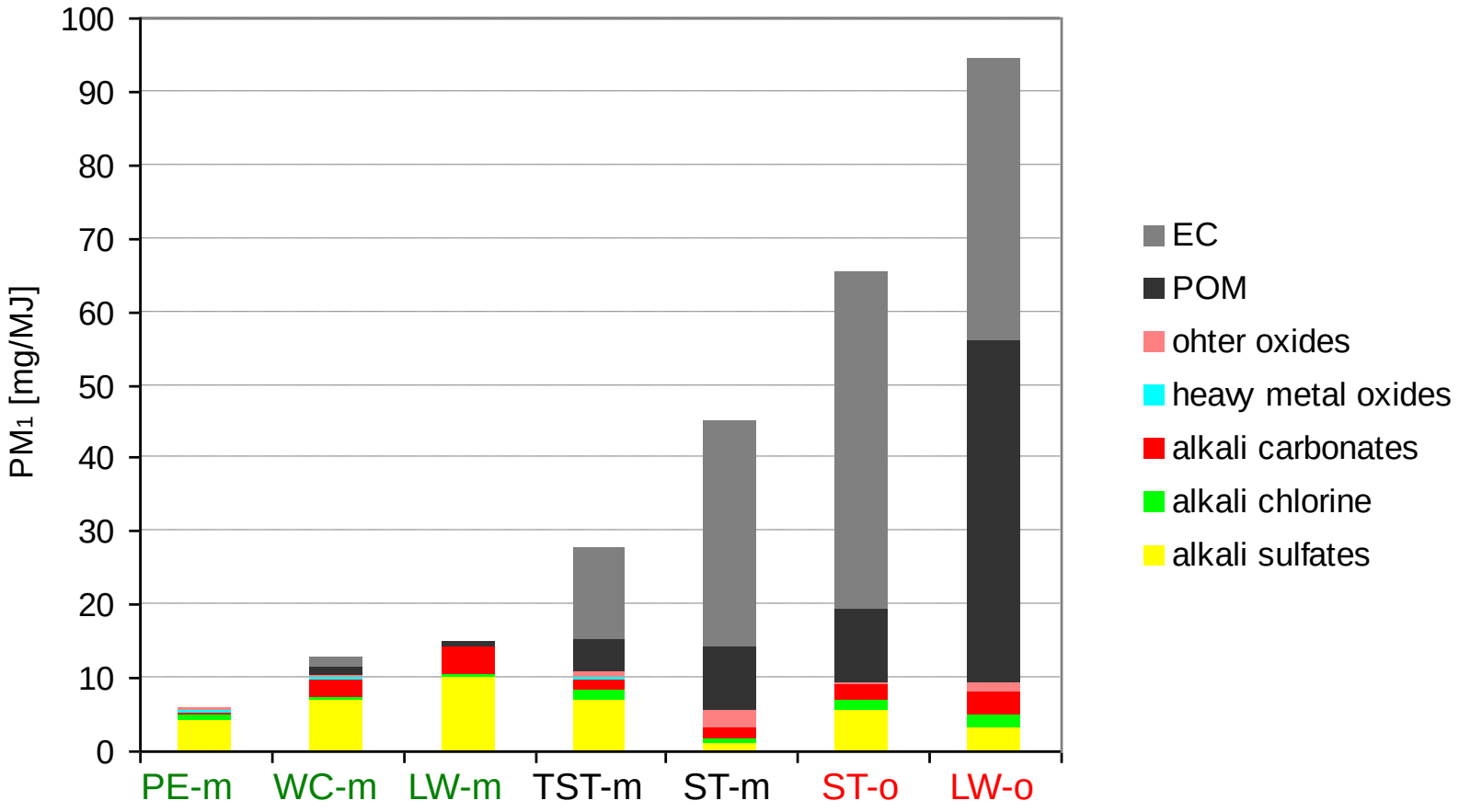
Small-scale biomass combustion system	Test run	CO [mg/MJ]	OGC [mg/MJ]	PM_1 [mg/MJ]
modern pellet boiler	1	47.1	2.5	6.2
	2	45.4	1.7	6.0
modern woodchip boiler	1	168.1	3.0	15.3
	2	182.2	5.4	13.6
modern logwood boiler	1	700.4	78.7	14.2
	2	793.1	62.4	17.6
modern logwood fired tiled stove	1	1,207.3	52.4	31.3
	2	1,007.5	69.2	28.0
modern logwood fired stove	1	1,048.2	94.2	47.2
	2	1,035.6	95.5	46.1
old logwood fired stove	1	2,355.4	223.9	74.2
	2	2,084.6	185.7	55.5
old logwood boiler	1	12,632.3	1,143.8	106.1
	2	8,969.4	650.8	98.6

Results – chemical analyses of PM_1 – total composition



Explanations: the OC concentrations were multiplied by 1.4 to obtain particulate organic matter (POM); data in wt% d.b.; PE-m … modern pellet boiler; WC-m … modern wood chip boiler; LW-m … modern logwood boiler; TST-m … modern tiled stove; ST-m … modern stove; ST-o … old stove; LW-o … old logwood boiler

Results – PM_1-emissions divided into their chemical compounds



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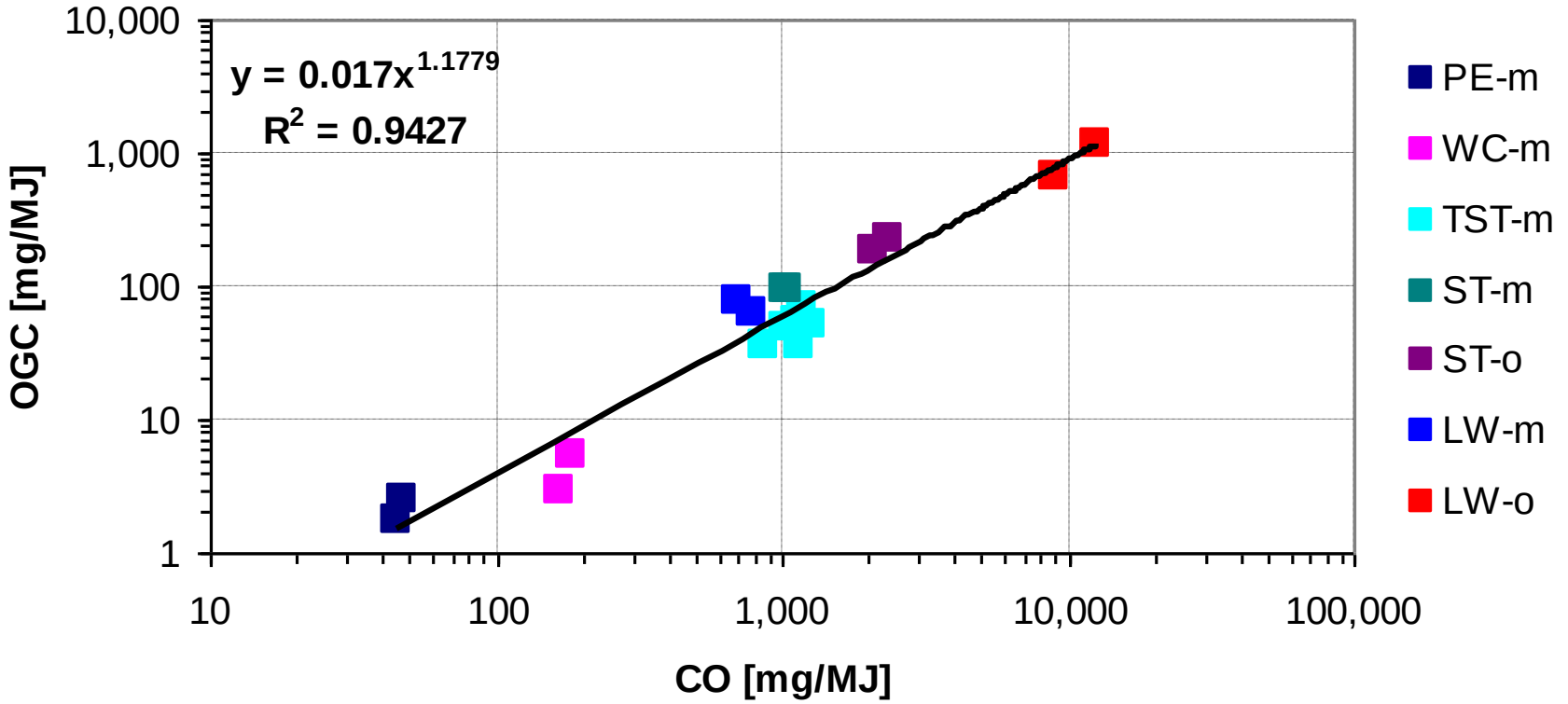
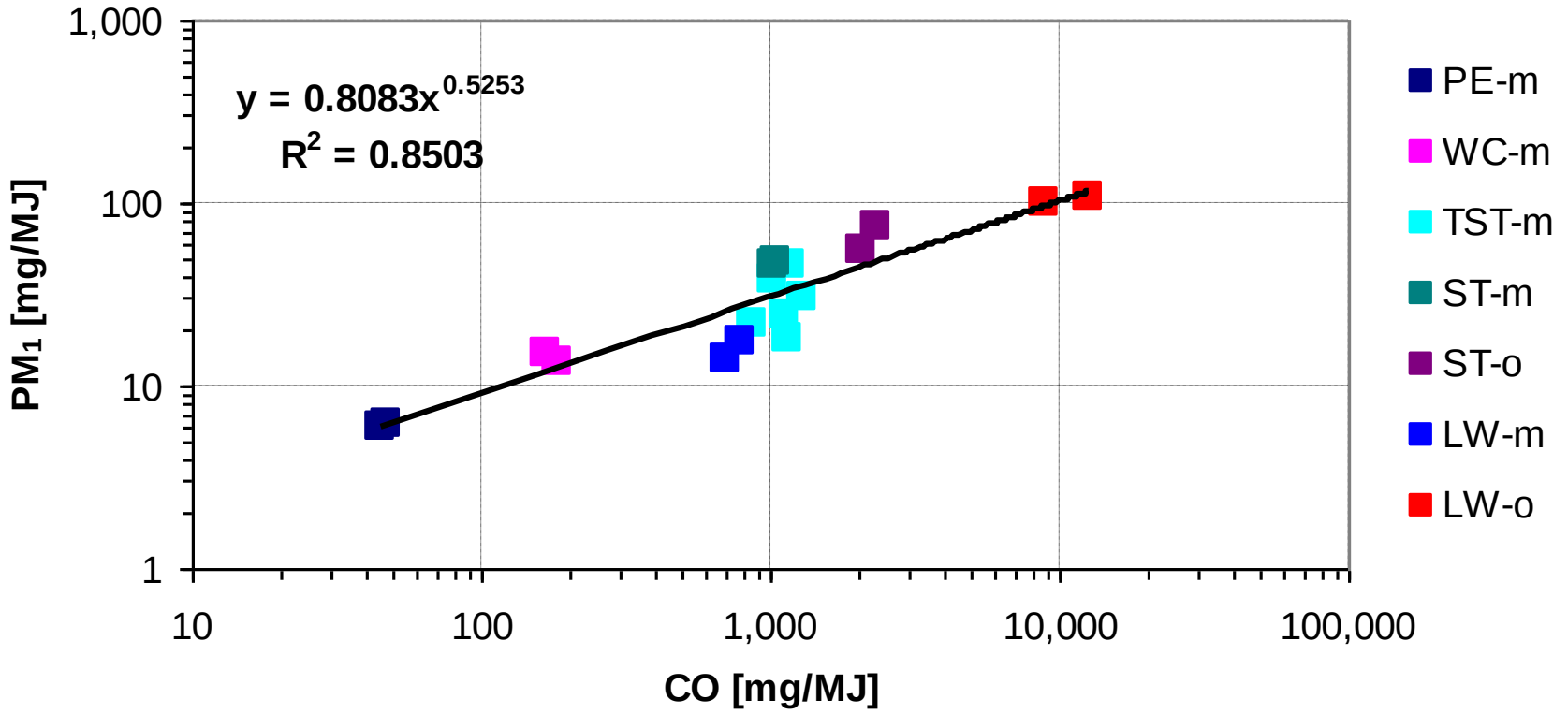
Results – correlation – CO vs. OGC



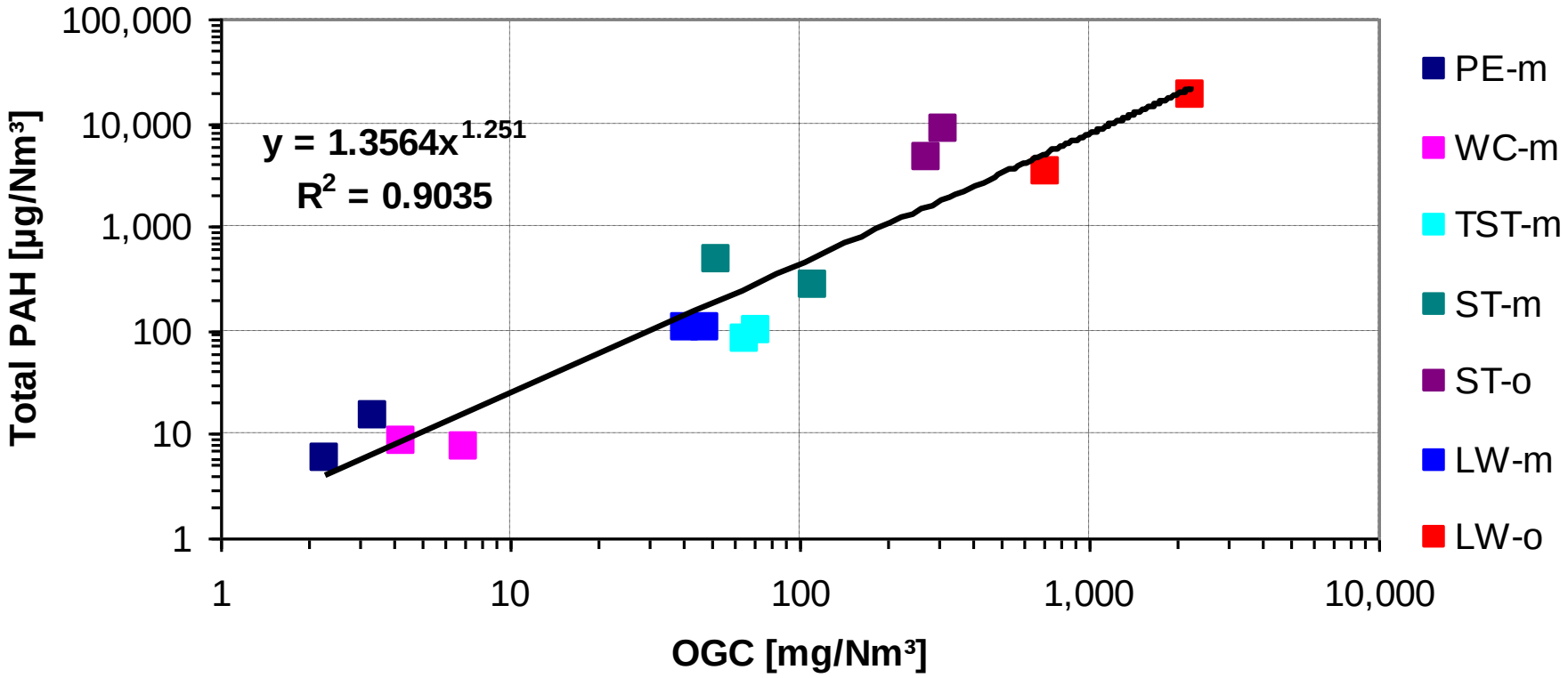
Explanations: mean values over the test runs performed; PE-m … modern pellet boiler; WC-m … modern wood chip boiler; LW-m … modern logwood boiler; LW-o … old logwood boiler; ST-m … modern stove; ST-o … old stove; TST-m … modern tiled stove; statistical evaluation: significance $p<0.05$

Results – correlation – CO vs. PM_1



Explanations: mean values over the test runs performed; PE-m … modern pellet boiler; WC-m … modern wood chip boiler; LW-m … modern logwood boiler; LW-o … old logwood boiler; ST-m … modern stove; ST-o … old stove; TST-m … modern tiled stove; statistical evaluation: significance $p<0.05$

Results – correlation – OGC vs. total PAH

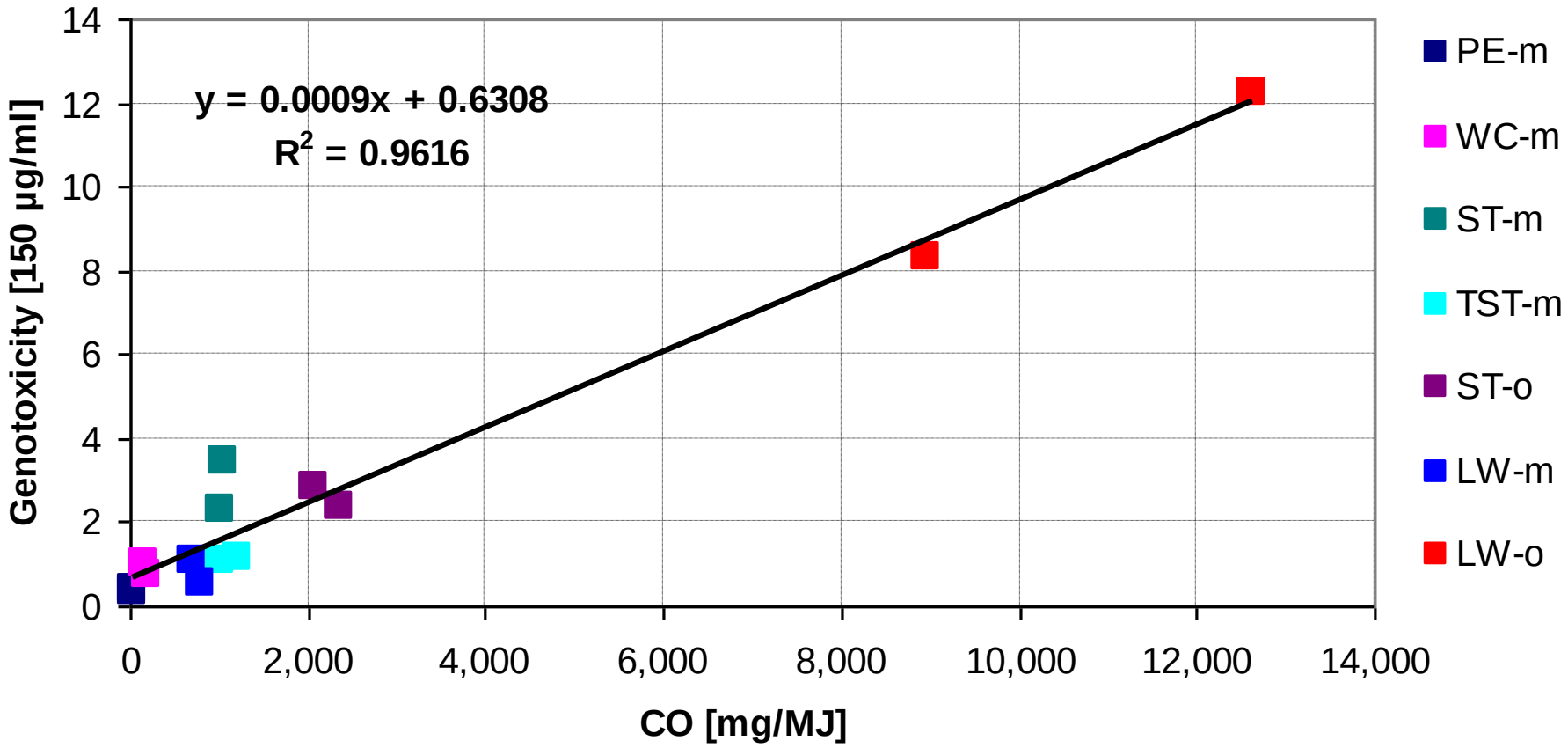


Explanations: PE-m … modern pellet boiler; WC-m … modern wood chip boiler; LW-m … modern logwood boiler; LW-o … old logwood boiler; ST-m … modern stove; ST-o … old stove; TST-m … modern tiled stove; statistical evaluation: trend $p<0.1$

Results – toxicological studies

- **Good agreement concerning the results for the 2 samples of each combustion system tested**
- **Dose dependent responses were gained, which means that with increasing dosage of PM_1 the reactions of the cells increase**
- **The old technology logwood boiler was in its own class to cause both inflammatory and cytotoxic responses and also caused markedly increased genotoxicity**
- **PM_1 emission samples from the wood chip and the pellet boiler caused the lowest response levels**

Results – correlation – CO vs. Genotoxicity



Explanations: PE-m … modern pellet boiler; WC-m … modern wood chip boiler; LW-m … modern logwood boiler; LW-o … old logwood boiler; ST-m … modern stove; ST-o … old stove; TST-m … modern tiled stove; statistical evaluation: significance $p<0.05$

Summary and Conclusions (I)

- **Burnout quality significantly decreased from**
  - **modern automated boiler systems (CO emissions: 45 to 800 mg/MJ) over**
  - **modern stoves and tiled stoves (CO emissions: 900 to 1,300 mg/MJ) to**
  - **old stoves (CO emissions: 2,100 to 2,400 mg/MJ) and logwood boilers (CO emissions up to 12,600 mg/MJ)**

- **Average PM_1 emissions ranged from approximately 6 mg/MJ (modern pellet boiler) to about 106 mg/MJ (old technology logwood boiler)**

- **Good correlations between gaseous and particulate emissions as well as PAH emissions exist**

Summary and Conclusions (II)

- **Inorganic fraction of PM_1 emissions mainly consists of alkaline metal salts (mainly K_2SO_4, KCl, K_2CO_3) and a small amount of heavy metal oxides (mainly ZnO)**
- **The concentrations of organic carbon and soot in the PM_1 emissions increase with decreasing burnout quality**
- **The burnout quality achieved as well as type of combustion (batch vs. continuous combustion) affects the relative harmfulness of the particulate emissions**
- **The composition from incomplete combustion seems to induce stronger toxicological effects than the composition from more complete combustion**

Recommendations to reduce PM_1 emissions from small-scale biomass combustion systems

- **Substitution of old residential biomass heating systems by new state-of-the-art technologies**
- **Further development of modern residential biomass combustion systems**
  - **stoves**
    - optimise burnout and minimise carbonaceous PM emissions especially during the ignition but also during the main combustion phase
  - **automatic boilers**
    - optimise burnout and minimise carbonaceous PM emissions during partial load operation and under transient combustion conditions

Acknowledgement

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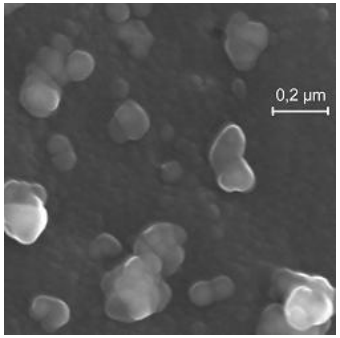

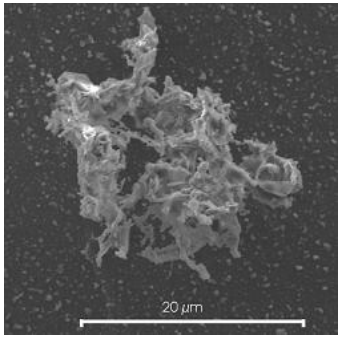

Thank you for your attention

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