Synergies in Gas Sampling Research Bioenergy Task 32 and Task 33

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Lucerne University of Applied Sciences and Arts
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Engineering & Architecture

1 T. Nussbaumer: Biomass combustion lab

2 S. Roth, G. Barroso: Pyrolysis gas sampling

3 P. Zotter, T. Nussbaumer: Cytotoxicity tests

Targets

1. increase **efficiency** for biomass heat and power

2. increase **fuel flexibility**

3. reduce the **impact on ambient air** by:

    1. Particulate Matter **PM_{10}** caused

        - by **primary PM**: primary organic aerosol (POA), BC, fly ash

        - NMVOC as precursors for **secondary** organic aerosol (SOA)

    2. **NO_X**

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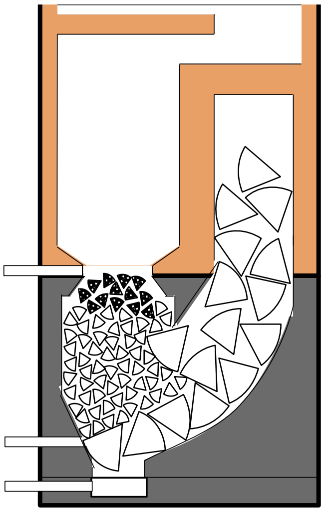
Combustion Devices

- *Log wood stoves (5–15 kW)*
    - Conventional type

Start-up: Ignition from the top

Combustion Devices

- *Log wood stoves (5–15 kW)*
  - Conventional type
  - Two-stage combustion type



Combustion Devices

- *Log wood stoves (5–15 kW)*
  - Conventional type
  - Two-stage combustion type

- *Log wood boilers (15–30 kW)*
  - Two-stage combustion type
  - Integration of heat storage tank

Liebi LNC

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- *Pellet boilers (15 –30 kW)*

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- *Pellet boilers (15 –30 kW)*
- *Moving grate boilers (150 kW)*
  - multi-sector grate
  - flue gas recirculation

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- *Pellet boilers (15 –30 kW)*
- *Moving grate boilers (150 kW)*
  - multi-sector grate
  - flue gas recirculation
- *Electrostatic precipitator (ESP)*
  - lab-scale for PM investigation
  - commercial for grate boiler

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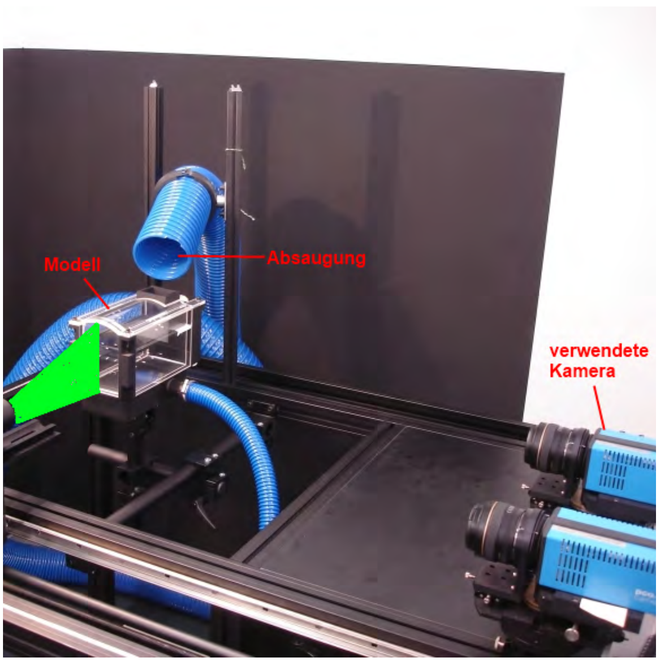
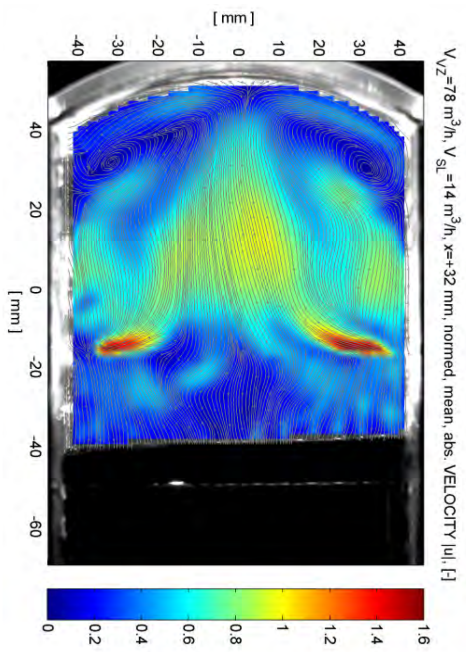
Fluid Dynamics Measurements

Particle Image Velocimetry (PIV)





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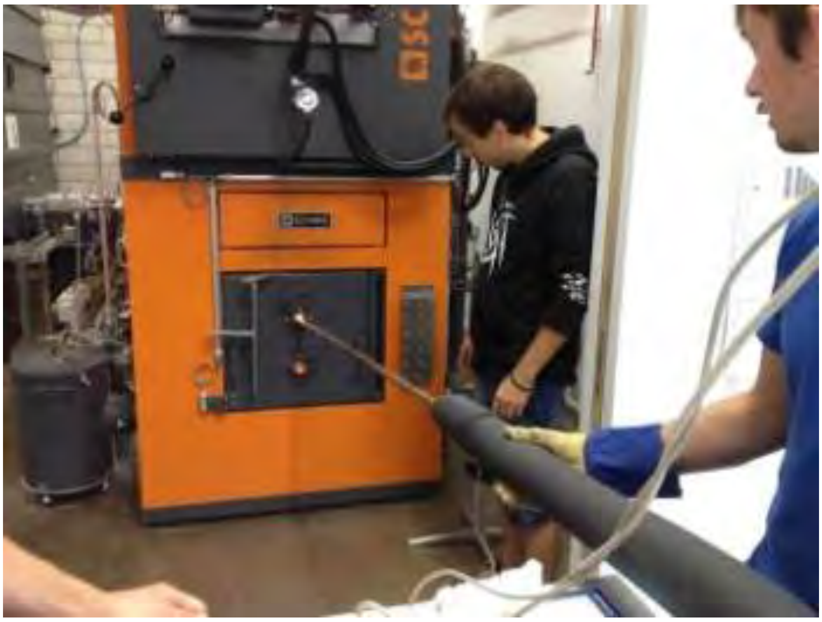
Gas sampling and analysis in fuel bed ('pyrolysis gas') and flue gas



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Motivation

1. Understanding the processes in the fuel bed
2. Pyrolysis gas: Validation of the 1D-Fuel-Bed-Model (FBM)
3. Flue gas: Validation of CFD model for gas phase reactions from fuel bed to stack

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Gas sampling and analysis

Parameter	Pyrolysis Gas		Flue Gas	
	Measurement	Modeling	Measurement	Modeling
T	Type K 0..1200°C	+	Type K 0..1200°C	+
O_2	Paramag. 0..25 %	+	Paramag. 0..25 %	+
H_2	TCP 0..25 %	+	-	+
CO_2	NDIR 0..25 %	+	-	+
CO	NDIR 0..30 %	+	NDIR 0..2500 ppm NDIR 0..5 %	+
CH_4	NDIR 0..5 %	+	(VOC – NMVOC)	+
VOC	FID 0..10 %	-	FID 0..10 %	-
NMVOC	(VOC – CH_4)	"Tar" = C_6H_6	FID 0..10 %	"Tar" = C_6H_6
H_2O	Cap. 0..50 %	+	-	+
NH_3	-	+	-	+
HCN	-	+	-	+
NO	-	+	NDIR 0..2500 ppm	+
PM mass	-	-	Filter Sampling	-
PM number/size	-	-	SMPS 20..700 nm OAS 0.3..20 µm	-

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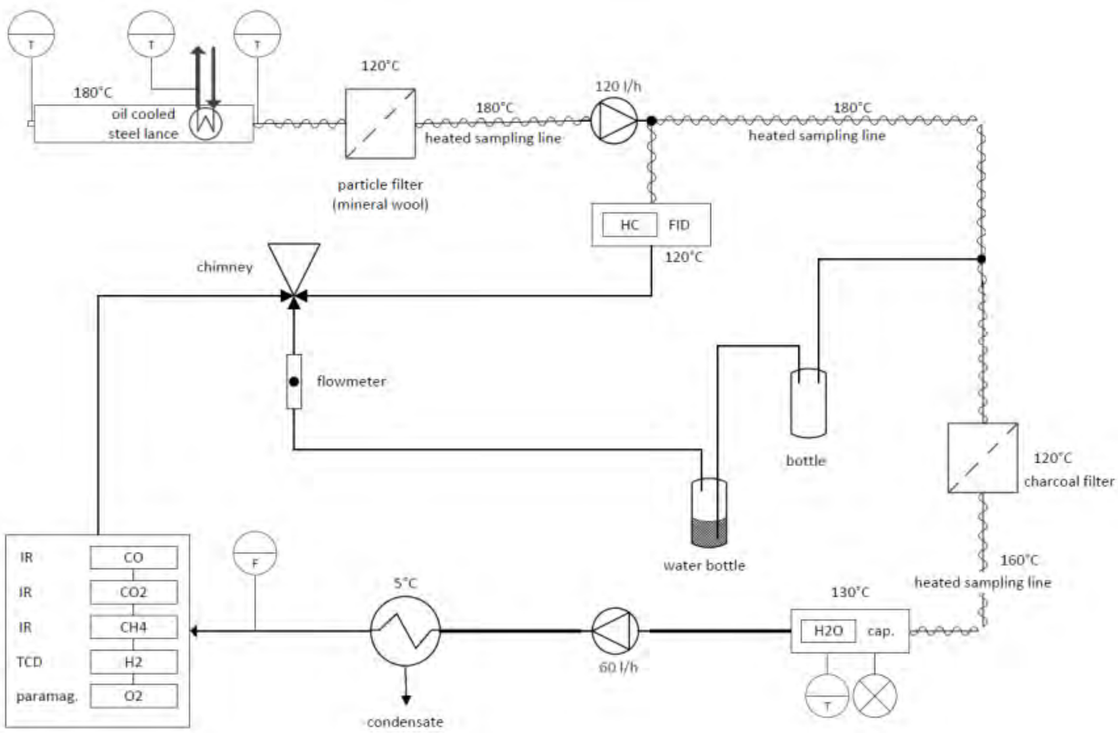
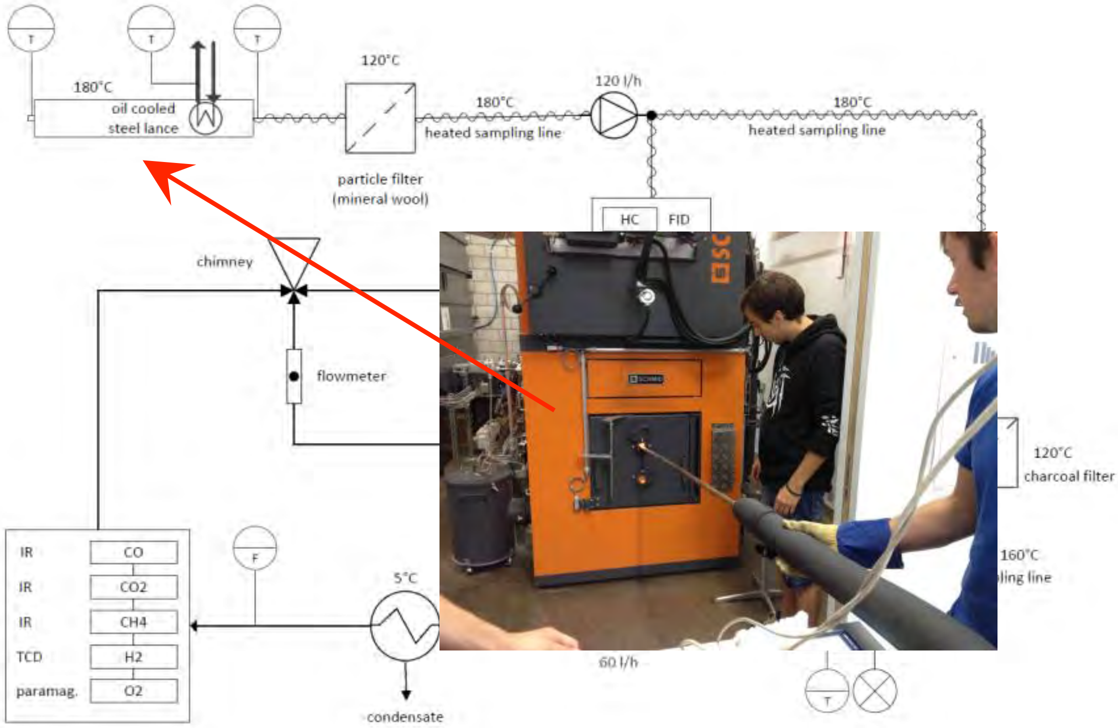
Pyrolysis gas sampling and analysis

Pyrolysis gas sampling and analysis



Pyrolysis gas sampling and analysis



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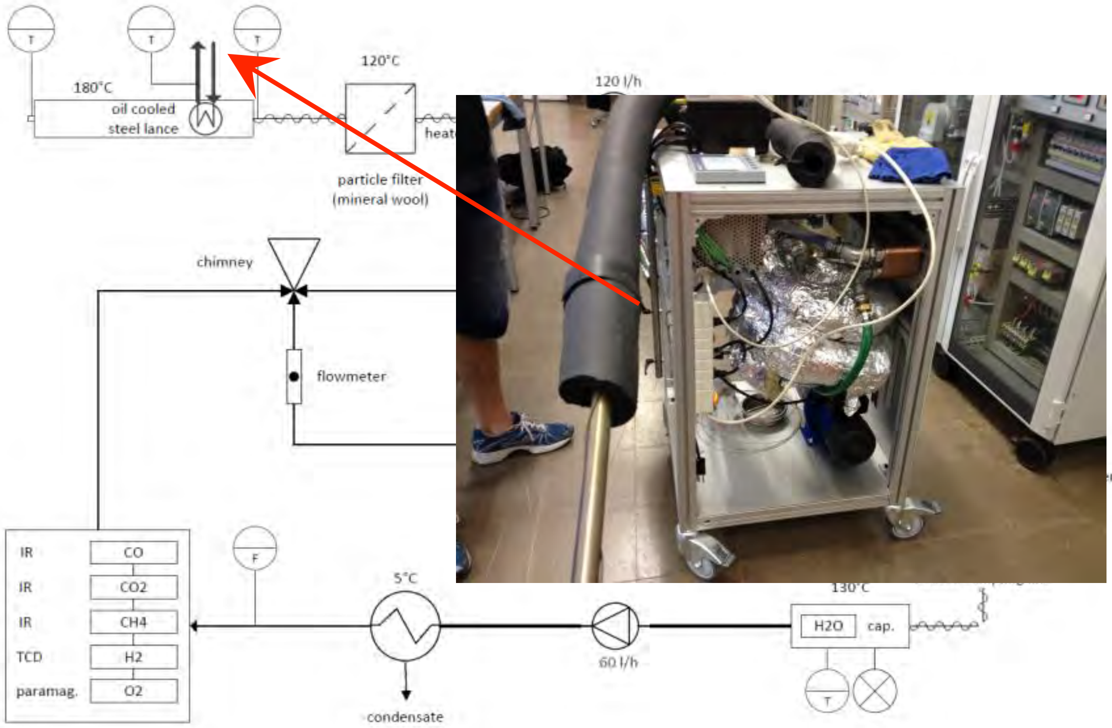
Pyrolysis gas sampling and analysis



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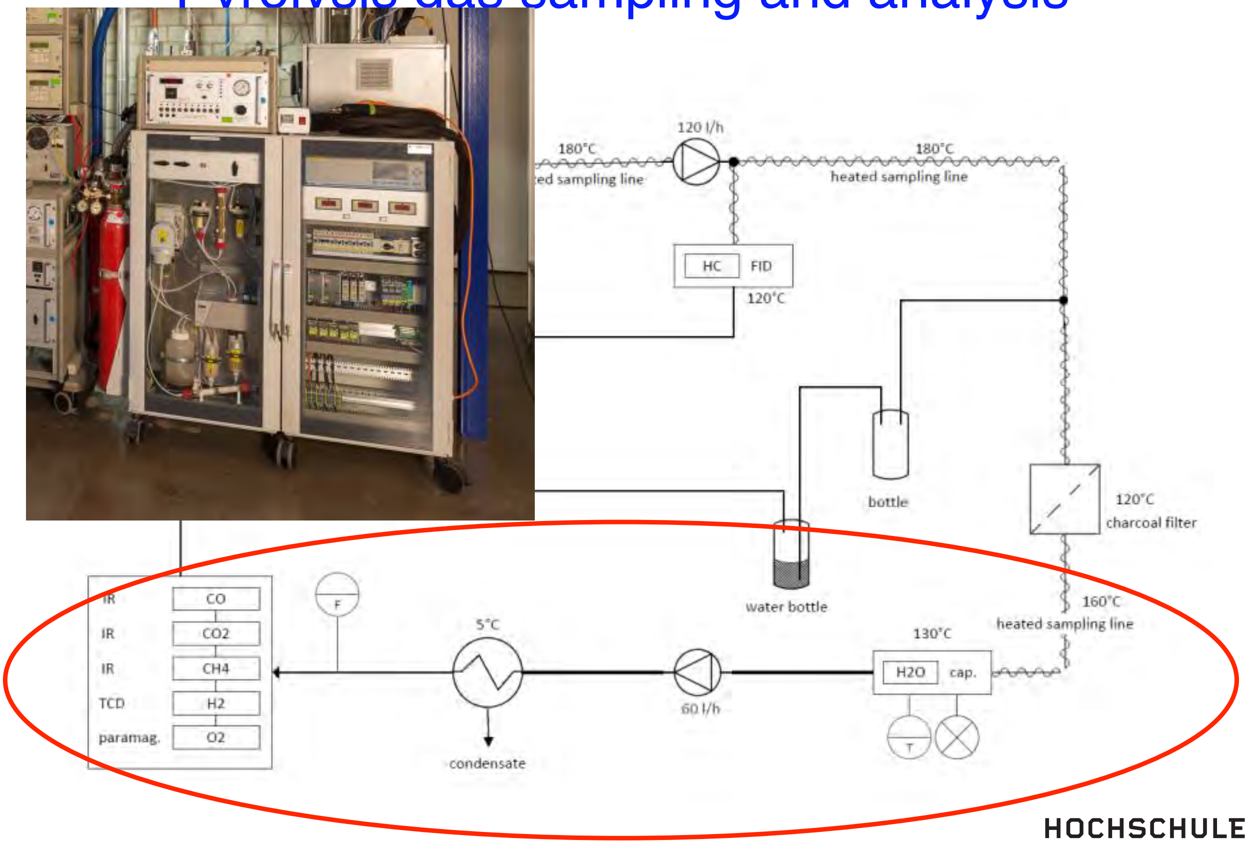
Pyrolysis gas sampling and analysis



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Practical experiences and challenges

- Filter clogging at 180°C due to condensation

- Position of sampling uncertain

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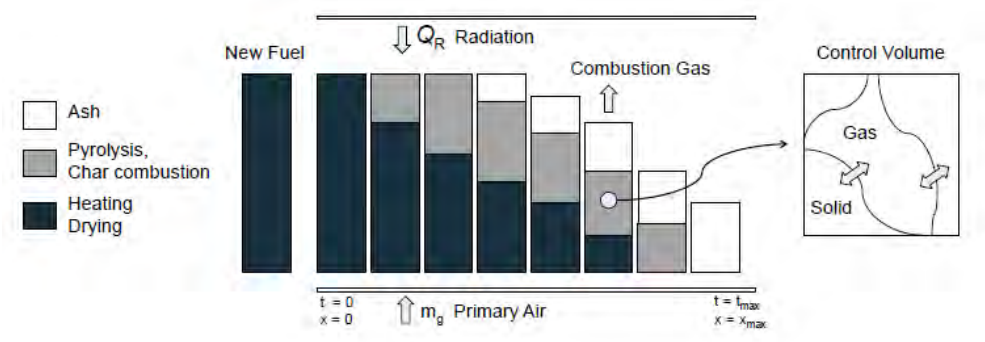
1D Fuel Bed Model



Concept of the walking column model:
A fuel column is observed during the walk over the moving grate – Lagrange formulation*.

*Martinez-Garcia, J. and T. Nussbaumer. Combustion Science and Technology, 2015. **187**(8): p. 1208-1228.

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1D Fuel Bed Model

Table: Chemistry of Fuel Bed Model - Solid Phase

Process				Global Reaction	
Drying	$Wood_{wet}$	→	$Wood_{Dry} + H_2O(g)$	$H_2O(l) \rightarrow H_2O(g)$	Eq. 1
			$Volatiles_1$	$CH_{1.4}O_{0.7}N_{0.0035} \rightarrow 0.34\ CH_4 + 0.62\ CO + 0.02\ H_2 + 0.04\ CO_2 + a\ NH_3 + b\ HCN + c \cdot NO + d\ N_2$	Eq. 2
Pyrolysis	$Wood_{Dry}$ ($CH_{1.4}O_{0.7}N_{0.0035}$)		$Tar + Volatiles_2$	$CH_{1.4}O_{0.7}N_{0.0035} \rightarrow 0.13\ C_6H_6 + 0.05\ H_2 + 0.22\ CO_2 + 0.26\ H_2O + a\ NH_3 + b\ HCN + c\ NO + d\ N_2$	Eq. 3
			$Char + Volatiles_3$	$CH_{1.4}O_{0.7}N_{0.0035} \rightarrow 0.76\ C(s) + 0.08\ CH_4 + 0.16\ H_2 + 0.16\ CO_2 + 0.38\ H_2O + a\ NH_3 + b\ HCN + c\ NO + d\ N_2$	Eq. 4
Char Combustion	$C(s) + \Theta^{-1}\ O_2$	→	CO, CO_2, HCN, NO, N_2	$C + \Theta^{-1}\ O2 \rightarrow 2(1 - \Theta^{-1})CO + (2/\Theta^{-1} - 1)CO_2 + a\ NH3 + b\ HCN + c\ NO + d\ N_2\ ; \Theta = f(T)$	Eq. 5

[1] Corresponds to a Massfraction of 0.2% N in the Wood

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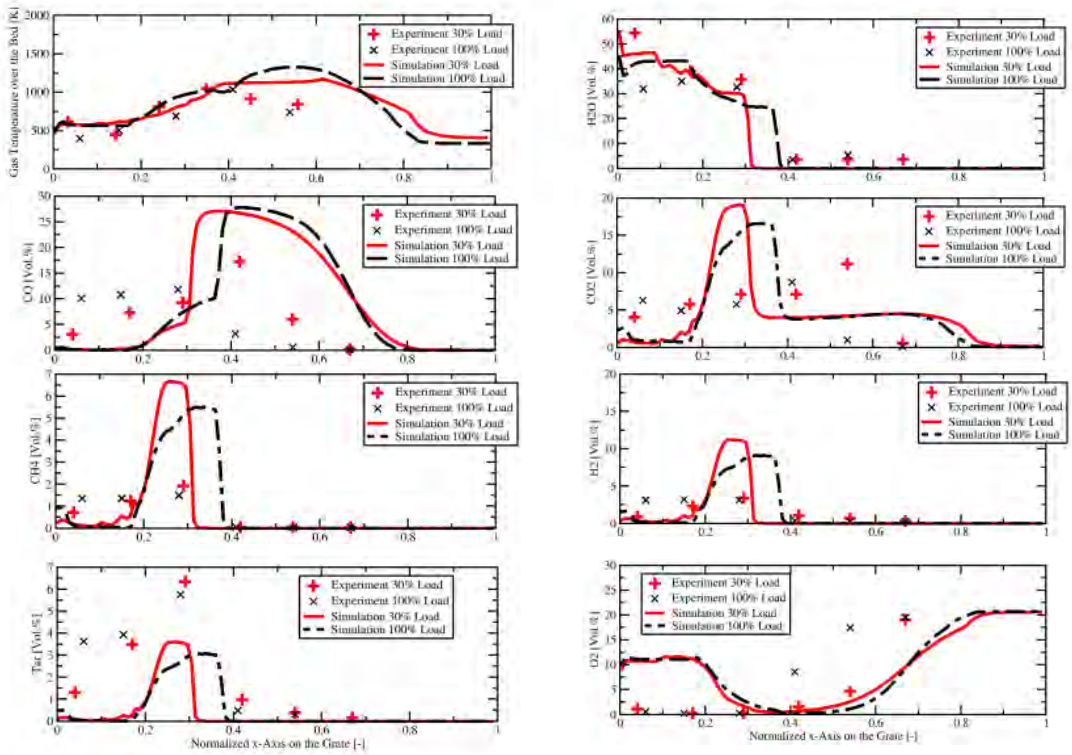
Validation 1D-EFBM with Experiments



[G. Barroso, S. Roth, T. Nussbaumer, 2016]

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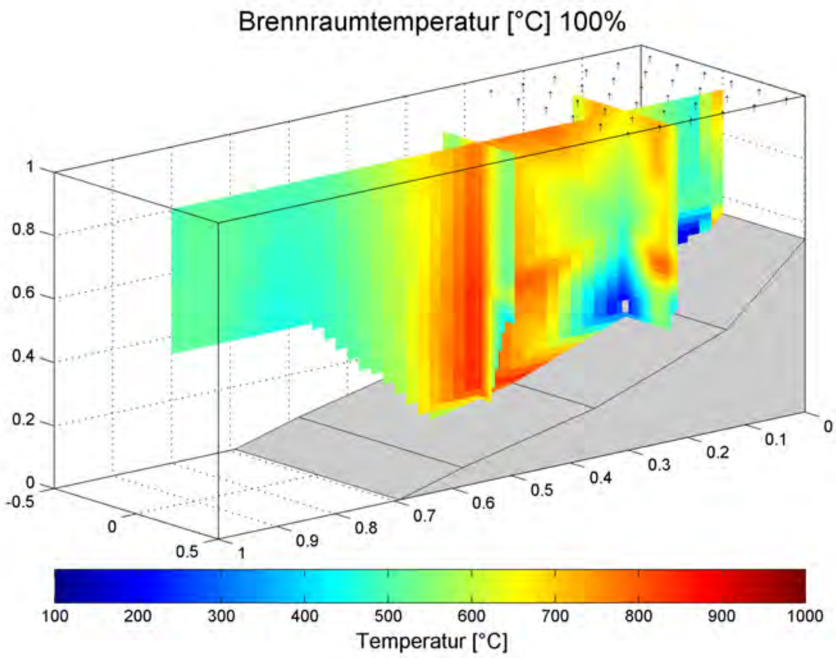
Results



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Conclusions - Further Steps

1. On-line detection of gas species (CO, H_2, CH_4, H_2O, VOC) from gasification section in a boiler is established

2. Data can be used for model validation

3. Compared to the measurements, the model predicts the wood gas flows out of the bed sharper. Explanations:

   – In the 1D-FBM only an upright velocity component out of the bed is simulated, while mixing along the bed is neglected.

   – Currently, the fuel particles are assumed as thermally thin, which is not accurate for practical fuel particles (e.g. > 10 mm)

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Synergies to Gasification

1. Comparison of model approaches and data for validation

2. Exchange of experience on sampling:
   – avoid clogging
   – increase positioning and accuracy

3. Interest on additional species:
   – "tar": indicators, other species than "NMVOC" ?
   – N-species for NO_X formation: NO, HCN, NH_3, ..

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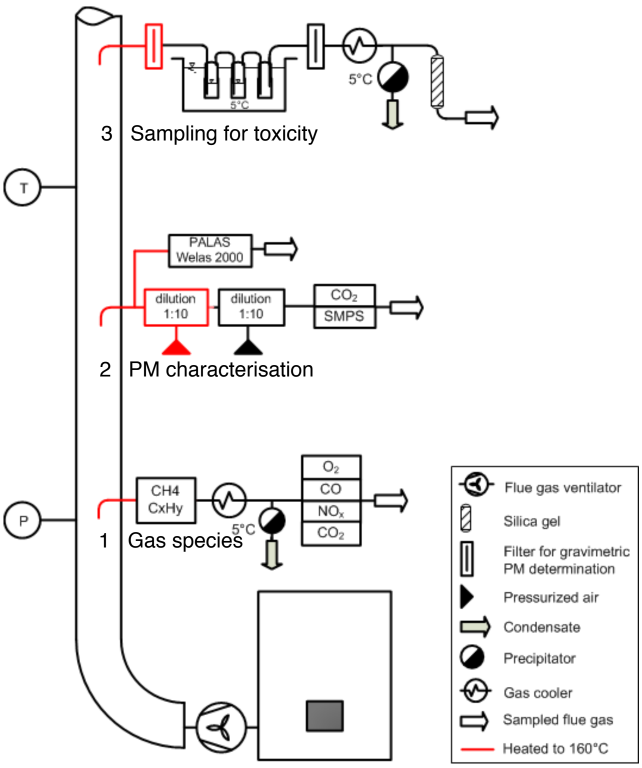
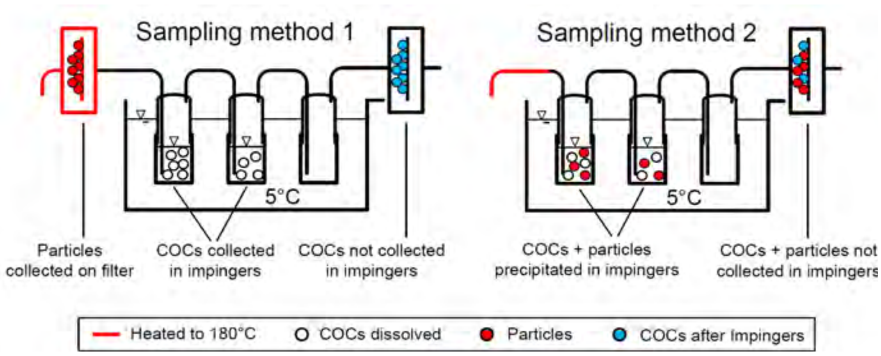
Experimental Setup for flue gas sampling

- Gas phase emissions:
  - *Combustion regime*
    - O_2, CO_2, CO
  - *Organic compounds with FID:*
    - CH_4, VOC, NMVOC
  - *Nitric oxide emissions:* NO
- Particles:
  - Solid PM mass according to VDI
  - Particle number concentration
  - Particle size distribution



Sampling in flue gas (after combustion)



Impingers

- *Impinger fillings:*
  - Cell growth medium
  - Sterile water
- *2 parallel sampling lines:*
  - Filter upstream of impingers → COC only
  - No filter upstream of impingers → COC plus solid PM

Picture of Sampling Setup

Analysis

1. TOC
2. Cell viability
   human lung cells (H187)
   24 h exposure

©dreamstime

M. Egli, S. Richard, CC ABSaT, HSLU

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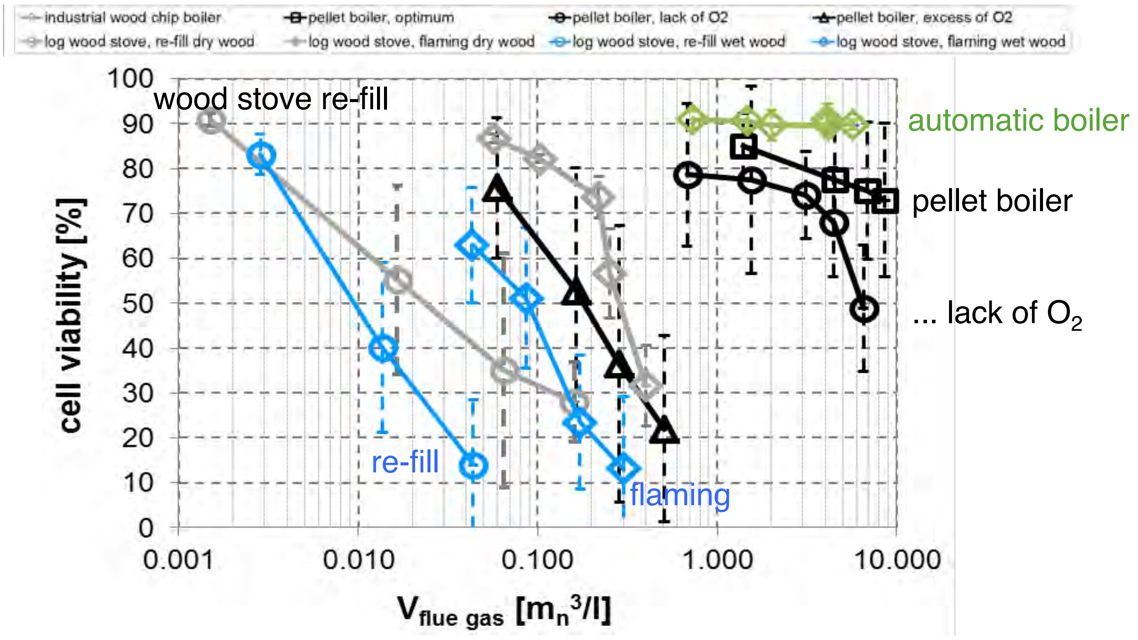
Results – Cell Viability of samples with COC



Cytotoxicity based on flue gas volume:

- Differences of more than factor 100
- Cytotoxicity decreases from highest to lowest NMVOC

[Zotter et al. 2016]

Synergies to Gasification

1. Comparison of toxicity of flue gas:

   a) combustion
   – influence of combustion type

   b) – gasification and combustion for heat
   – gasification and IC engine application

Acknowledments

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International Energy Agency IEA Bioenergy Task 32

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