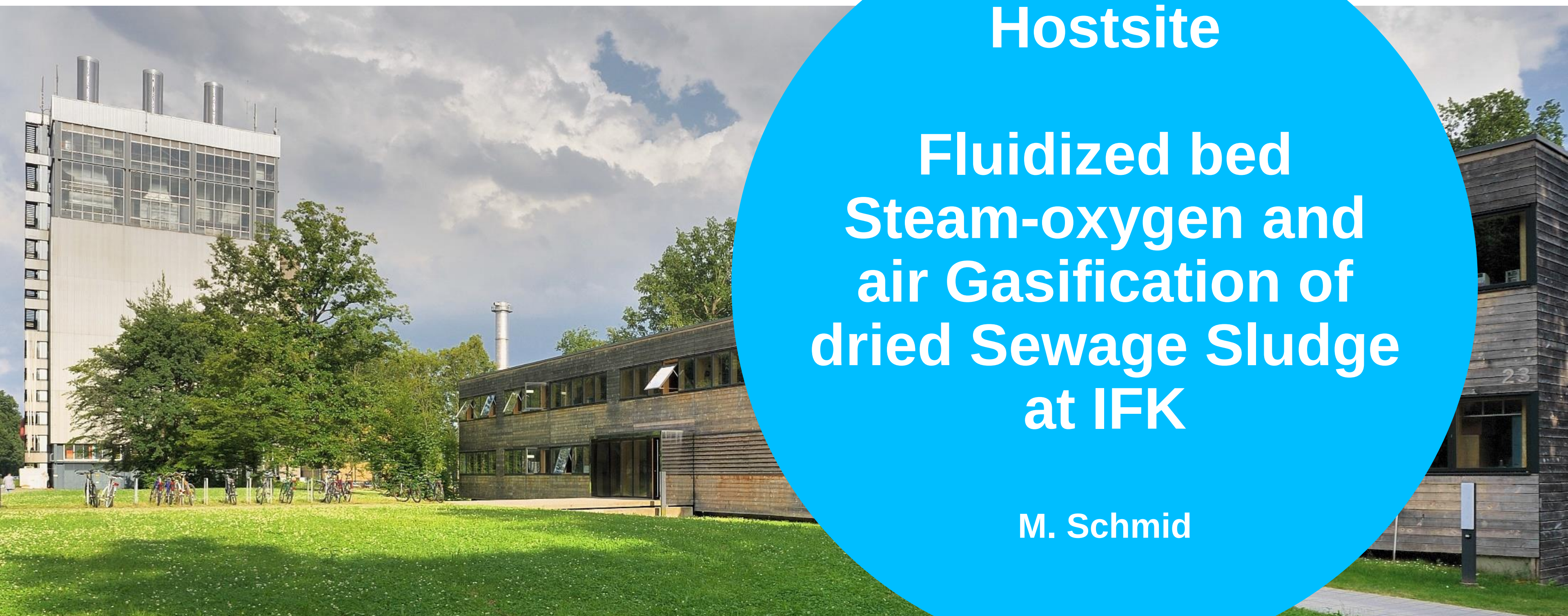
University of Stuttgart
Institute of Combustion and Power Plant Technology
Prof. Dr. techn. G. Scheffknecht



Hostsite

Fluidized bed Steam-oxygen and air Gasification of dried Sewage Sludge at IFK

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Fluidized Bed Processes
- ✓ Gasification
- ✓ Combustion
- ✓ Calcium Looping (CaL)
- ✓ Chemical Looping (CLC)

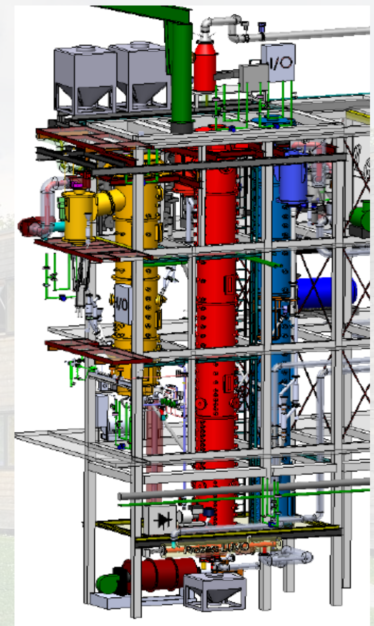
Fuels
- ✓ Biomass, Residues
- ✓ Coal

Gas measurement
- ✓ Permanent gases
- ✓ H_2S, NH_3, HCl
- ✓ tar

20 kW_{th} electrically heated DFB System

Tar generator test rig

200 kW_{th} DFB Pilot Facility



Flameless oxidation
- ✓ Liquid fuels
- ✓ Producer gas

Gas/ Tar Analysis

Cold Model Analyses

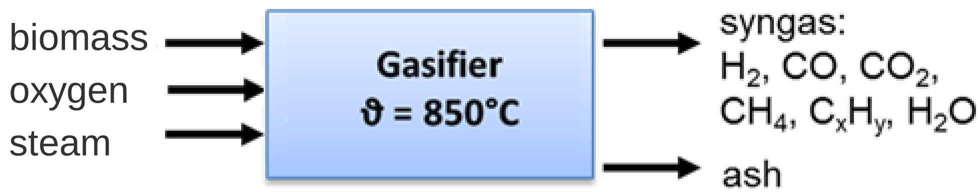
Modelling and Simulation

Hostsite

at IFK University of Stuttgart

- When: ~ February 2018
- What: BFB steam oxygen and air gasification of sewage sludge
- Goals: massbalance over gasifier
  - With and without sorbens (e.g. CaO) for tar and H_2S, HCl reduction in syngas
  - Variation of steam, temperature
  - Elements to be considered:
    - C,H,O
    - S, Cl, N
    - P, Fe, Ca, Hg, Zn, Cu …

Steam-oxygen fluidized bed gasification



Advantages:

- N_2-free syngas is provided (N_2-lean with N_2 containing fuels)
- Syngas is suitable as feedstock for chemical synthesis
- Only one fluidized bed reactor is needed
- Technology is readily available from coal gasification
- O_2 enhances carbon and tar conversion
- When coupling with an water electrolysis excess O_2 can be used in gasifier

Composition of dried sewage sludge and comparison with other fuels

Wood pellets

Straw pellets

Dried sewage sludge

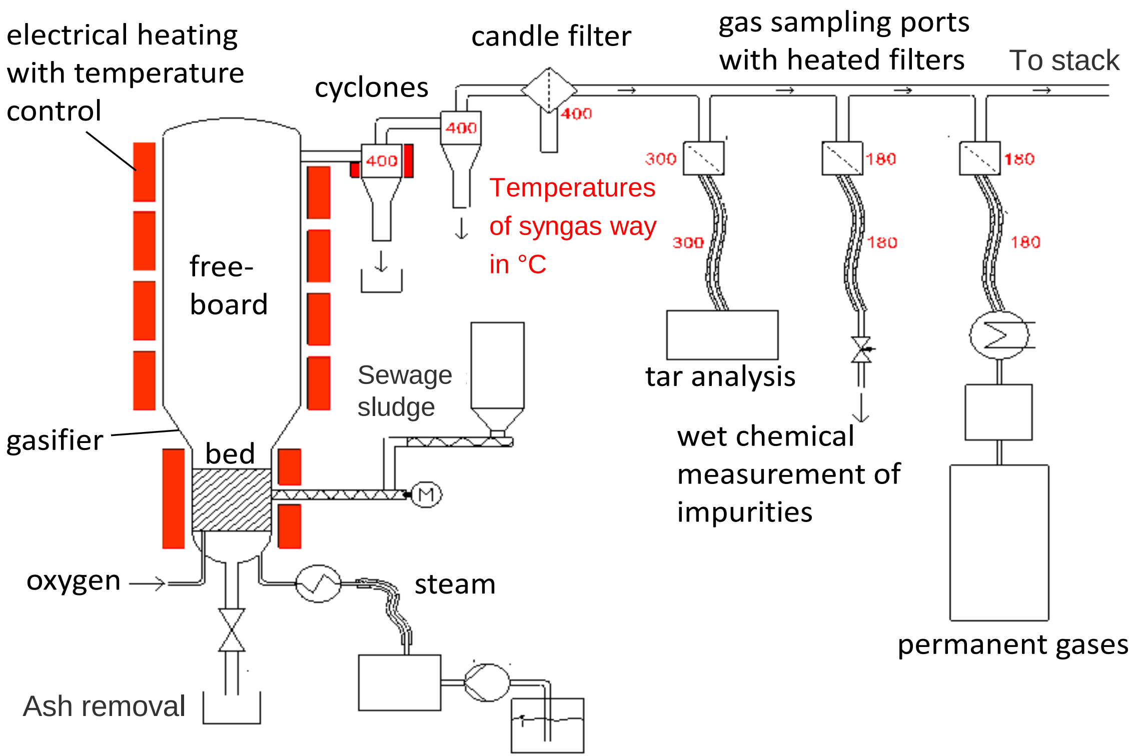
in wt-%	proximate analysis		elemental analysis waf					
	moisture	**ash wf**	**C**	**H**	**O**	**N**	**S**	**Cl**
wood pellets	9.8	0.1	50.8	6.3	42.9	-	-	-
straw pellets	10.3	5.7	49.3	6.4	42.8	0.8	0.2	0.5
dried sewage sludge	6.5	47.6	51.0	6.9	32.1	7.5	2.4	0.2

Composition of Sewage Sludge Ash

Probenkennzeichnung	getrockneter Klärschlamm 4. Charge
Hauptelemente als Oxide	**a (550°)**
Kalziumoxid (CaO), %	19,5
Eisenoxid (Fe_2O_3), %	9,70
Kaliumoxid (K_2O), %	1,57
Magnesiumoxid (MgO), %	2,61
Manganoxid (MnO_2), %	0,259
Natriumoxid (Na_2O), %	0,329
Phosphoroxid (P_2O_5), %	15,9
Schwefeltrioxid (SO_3), %	3,98
Siliziumoxid (SiO_2), %	28,0
Strontiumoxid (SrO_2), %	0,097
Titanoxid (TiO_2), %	0,570
Summe Oxide, %	*93,8*
Kohlenstoff	**a (550°)**
Gesamt (TC), %	1,50
organisch + elementar (TOC), %	0,040
anorganisch (TIC), %	1,46
Kohlendioxid (CO_2), %	5,34
Summe TOC + CO_2, %	*5,38*
Summe Oxide +TOC + CO_2, %	*99,2*

Probenkennzeichnung	getrockneter Klärschlamm 4. Charge
Kurzanalyse	**an (<0,25 mm)**
Analysenfeuchte (N_2+106°C), %	4,72
Spurenelemente	**wf**
Arsen (As), mg/kg	9,57
Beryllium (Be), mg/kg	0,597
Cadmium (Cd), mg/kg	1,68
Kobalt (Co), mg/kg	2,97
Chrom (Cr), mg/kg	377
Kupfer (Cu), mg/kg	515
Quecksilber (Hg), mg/kg	0,403
Molybdän (Mo), mg/kg	7,49
Nickel (Ni), mg/kg	25,3
Blei (Pb), mg/kg	35,8
Antimon (Sb), mg/kg	2,69
Selen (Se), mg/kg	13,0
Zinn, mg/kg	134
Thallium (Tl), mg/kg	2,67
Vanadium (V), mg/kg	30,8
Zink (Zn), mg/kg	1010

Methods – Experimental facility



- bubbling fluidized bed reactor
- electrically heated
- bed diameter 0.15 m
- 3.5 m high, 10 kg bed material
- fuel input 20 kW: 3..10 kg/h
- online measurement of permanent gases (H_2, O_2, CO, CO_2, CH_4, C_xH_y)
- wet chemical measurement of tar and impurities (HCl, NH_3, H_2S)

Experimental parameters

Gasifier temperature **ϑ** = **850°C**

- high temperature promotes tar and char coversion
- still below ash melting points

Steam to carbon ratio **S/C** = **1 mol/mol** (for wood S/B ≈ 0,6 kg/kg)

- as less steam a possible to enhance the overall efficiency
- but sufficiant for full carbon conversion and significant tar reforming

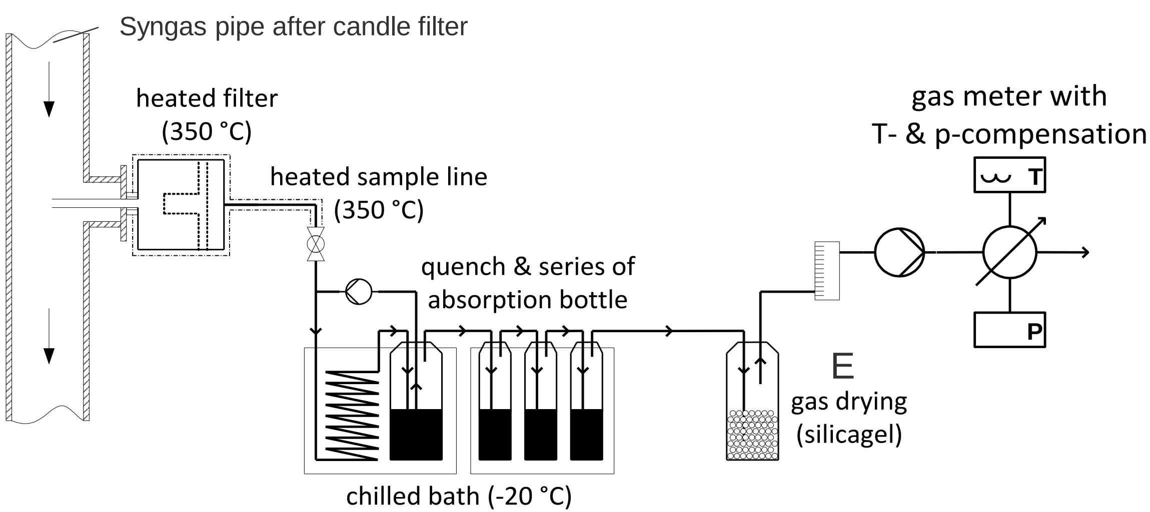
Equivalence ratio **ER** (air ratio) of **0.25**

- in an industrial gasifier, ER is adjusted to reach the desired gasifier temperature
- in the electrically heated experimental facility ER is set according to thermodynamical calculations for autothermal operation at adiabatic conditions
  → electrical heating was only used for heat loss compensation

Bed material: **Silica sand** for wood and straw, **ash** for sewage sludge

Methods – wet chemical impurity and tar measurement

Tar measurement arrangement

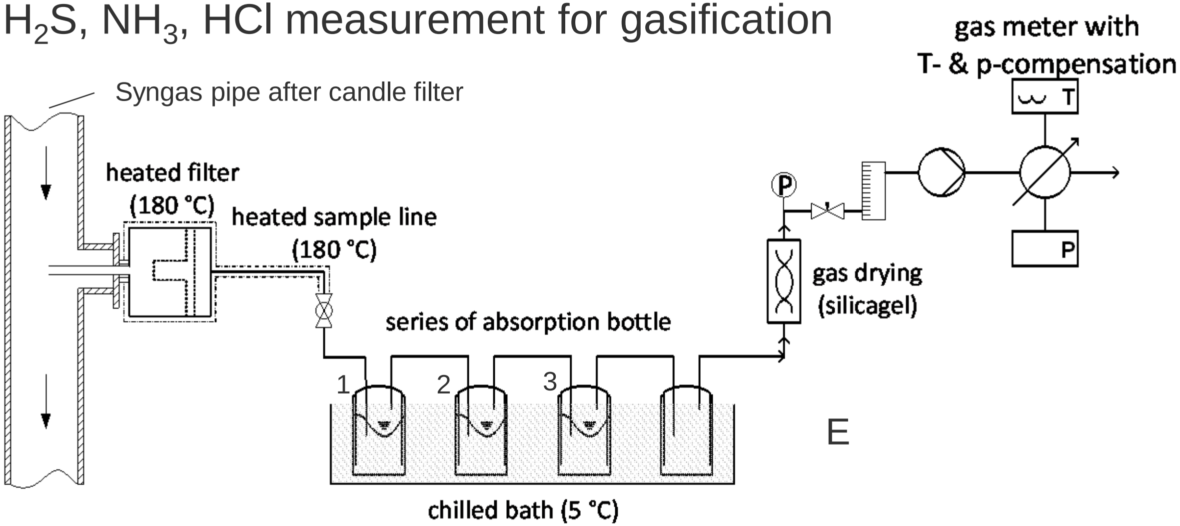


Further explanations:
Visual Presentation 2CV.3.31
D. Schweitzer, M. Schmid, A. Gredinger, R. Spörl., G. Scheffknecht: Gasification of waste biomasses: Measurement of pollutants in product gas, EUBCE 2017

DIN CEN/TS15439 (tar protocol)
- Absorption liquid: Isopropanol
- Liquid is sampled and analysed
  Gravimetrically (GC-MS also possible)

Methods – wet chemical impurity and tar measurement

H_2S, NH_3, HCl measurement for gasification



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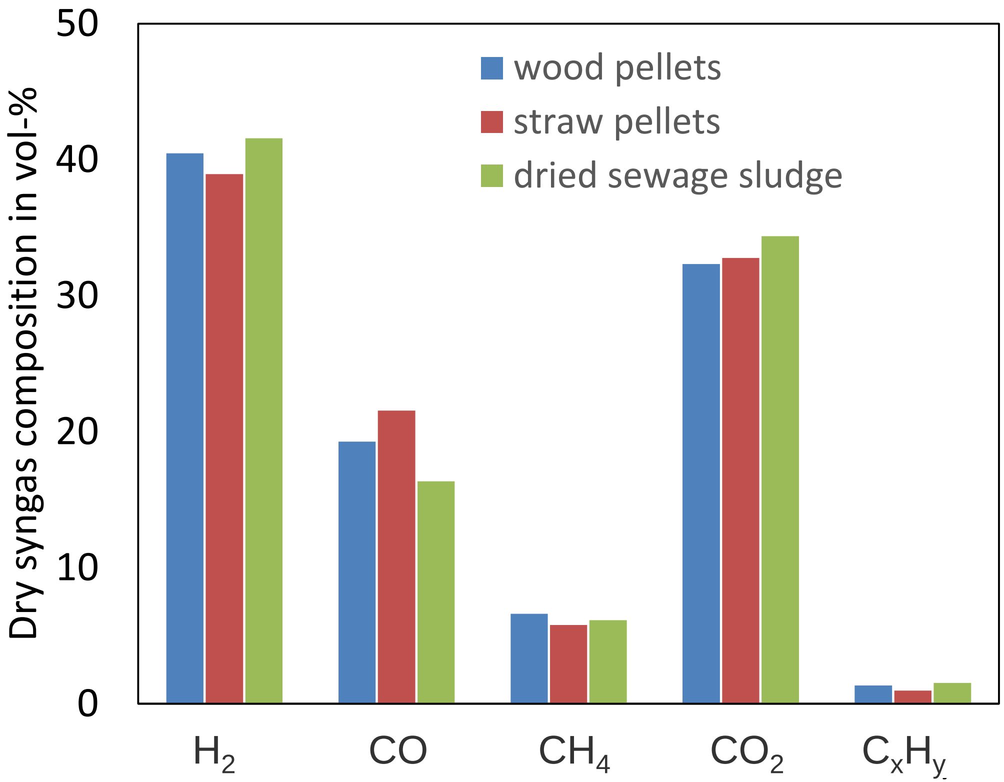
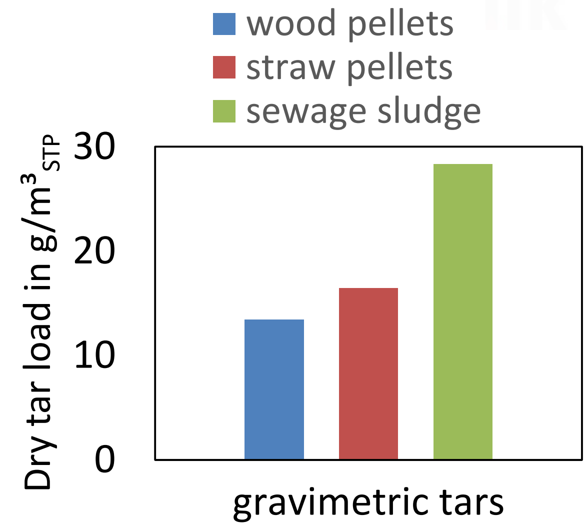
- H_2S: DIN 51855-4 (iodometric titration)
- NH_3: DIN EN ISO 11732 (indophenol method)
- HCl: Coulometric analysis

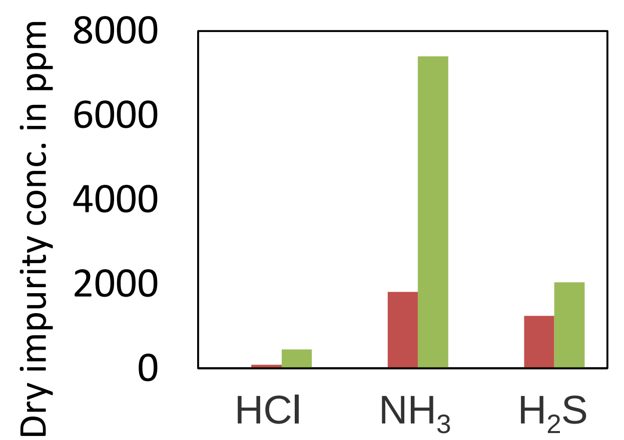
	H_2S	NH_3	HCl
Tar removal solution *bottle 1*	Isopropanol, H_2SO_4	Isopropanol, NaOH	-
absorption solution *bottle 2+3*	Zinc acetate	1 mol/l H_2SO_4	H_2O

Experimental results – dry syngas composition

Permanent gases and impurities







- Steam content in syngas approx. 30 vol.-$\%_{wet}$

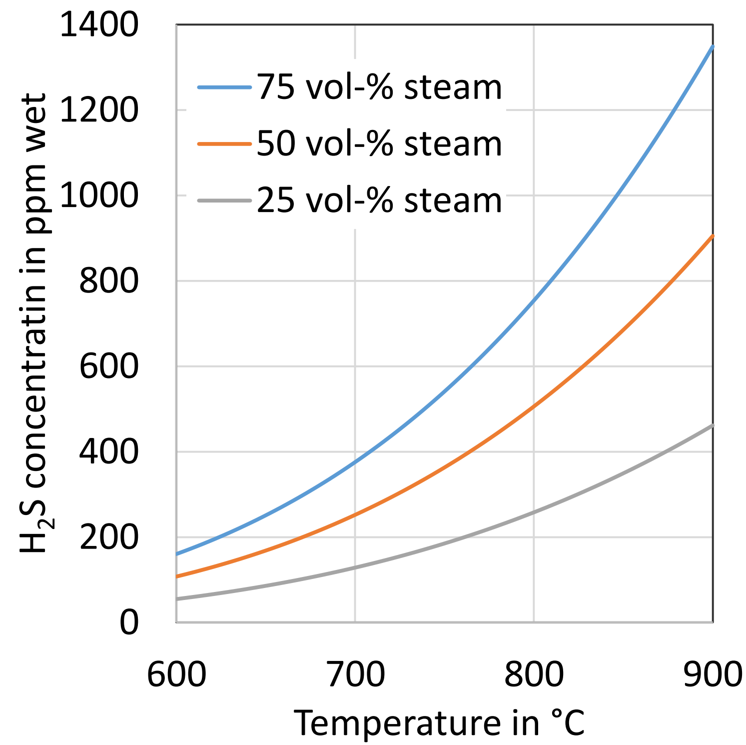
Bed additives for impurity reduction

Limestone ($CaCO_3$) is a cheap and highly available additive

- At the gasification conditions of this work, limestone is calcined to CaO
- As known from preliminary work in SEG, CaO was found active as a tar cracking catalyst
- CaO also absorbs sulfur in reductive conditions and thus performs in-situ desulfurization:

$$CaO + H_2S \rightarrow CaS + H_2O$$

Equilibrium concentration of H_2S in a system of CaO, S, H_2, H_2O, N_2

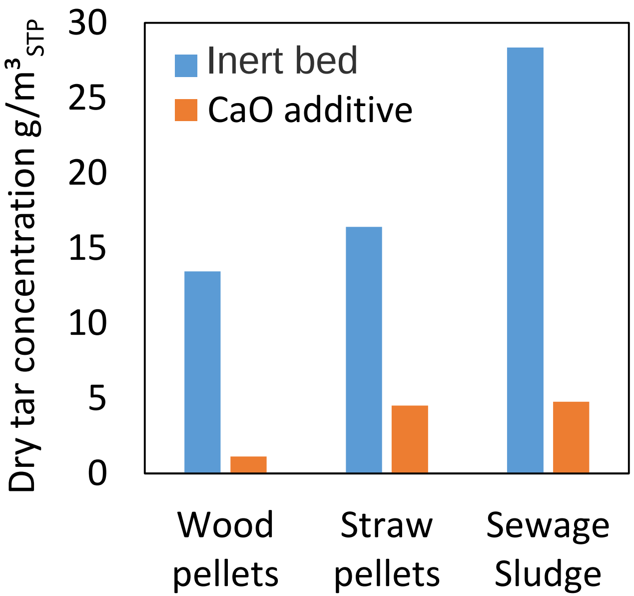


Experimental results – bed additives for impurity reduction

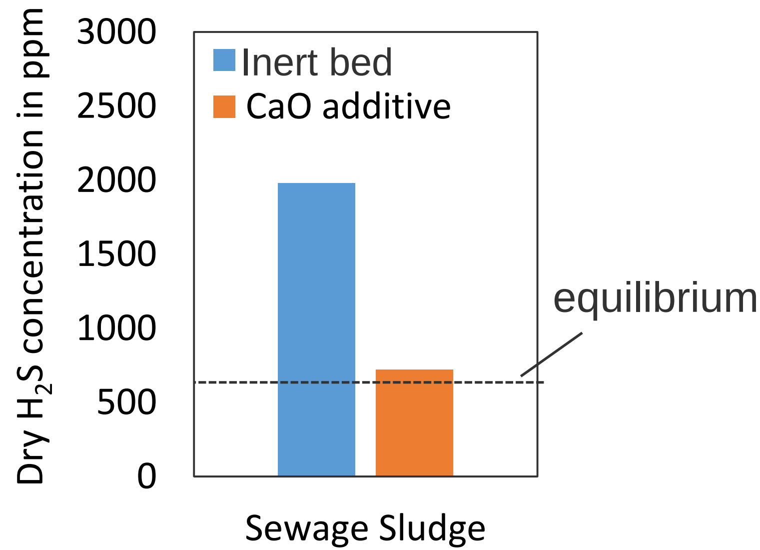
Experimental parameters: ER= 0.25, ϑ = 850°C, S/C=1 (approx. 30 vol-% steam)

	Inert bed	Active bed
Wood pellets, straw pellets	100 % silica sand	100 % CaO
Sewage sludge	100 % ash	25 % CaO + 75% ash

CaO additive influence on tar



CaO additive influence on H_2S



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Thank you!

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