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WasteEng 24

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ENTRAINED FLOW GASIFICATION OF SEWAGE SLUDGE TO REDUCE HEAVY METALS IN THE REMAINING ASH

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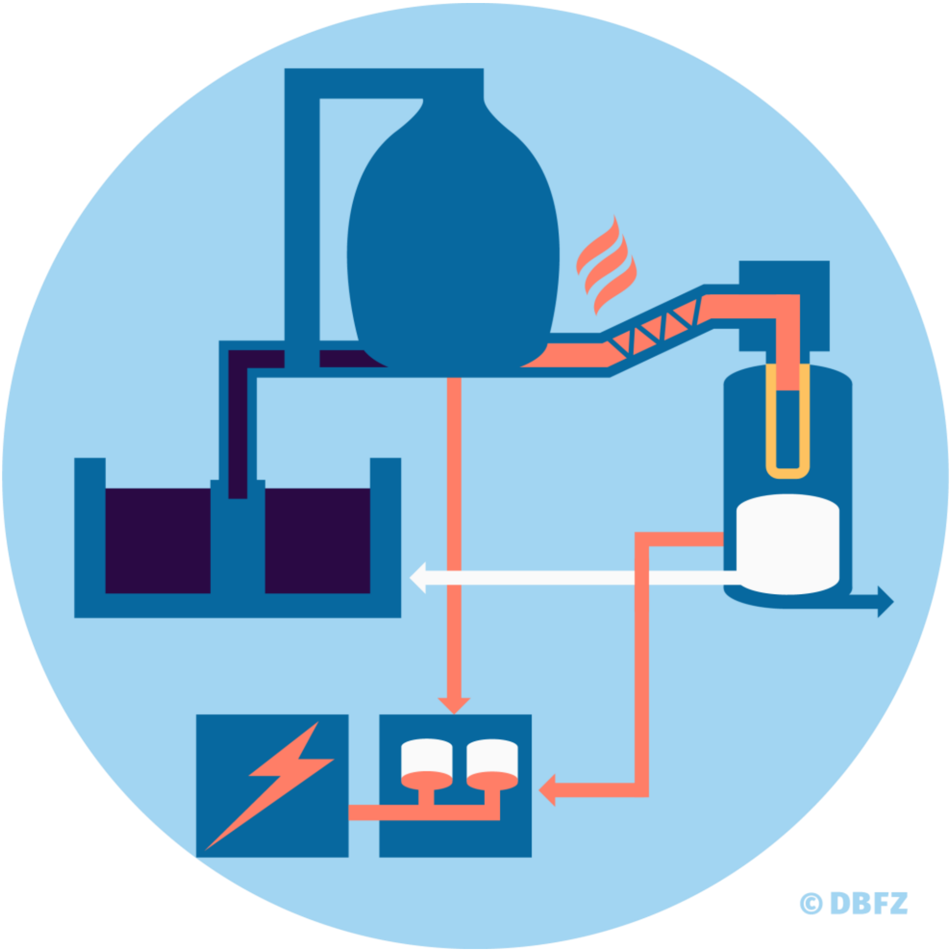
Agenda

Content of This Presentation for the 10th WasteEng24

- Concept of Sewage Sludge Valorization
  - Centralized Stationary Fluidized Bed Combustion
  - Decentralized Entrained Flow Gasification
- Experimental Setup and Methodology
- Experimental Results
  - Air Ratio
  - Additives
  - Temperature
  - High Iron or High Aluminum Sewage Sludge
- Conclusions and Outlook



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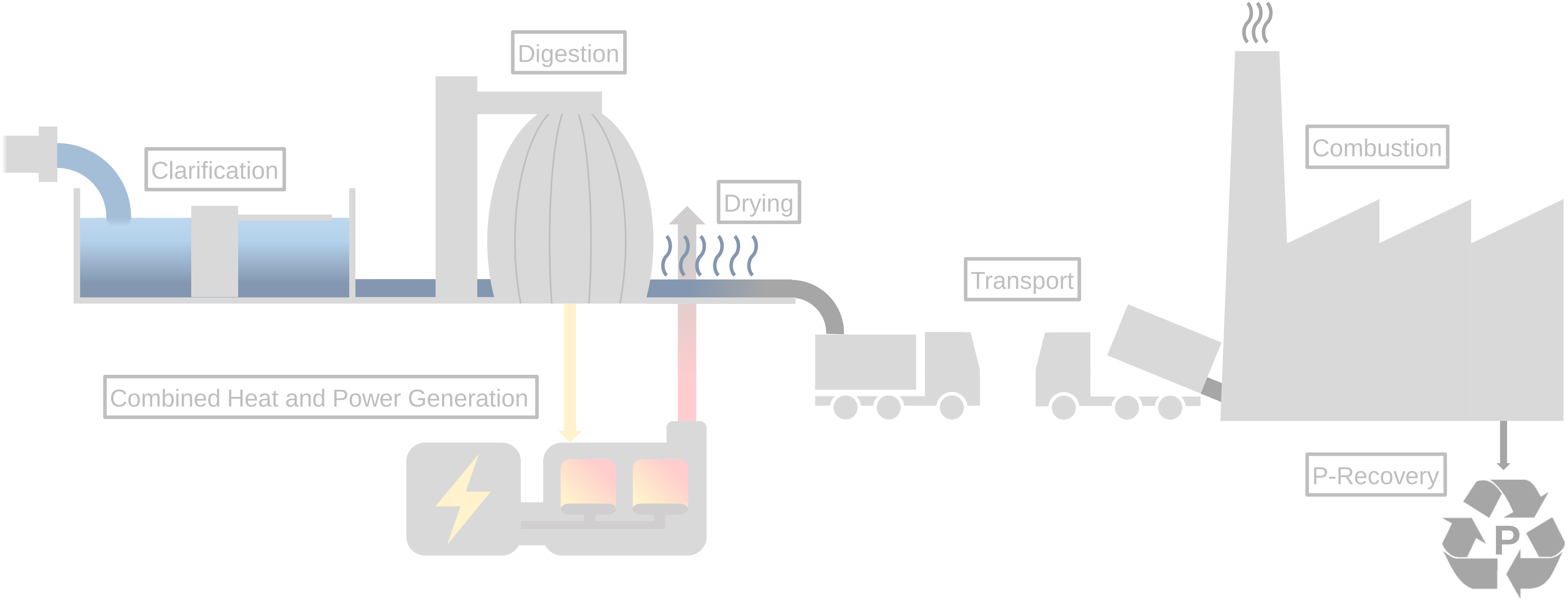
Concept of Sewage Sludge Valorization

Centralized Stationary Fluidized Bed Combustion



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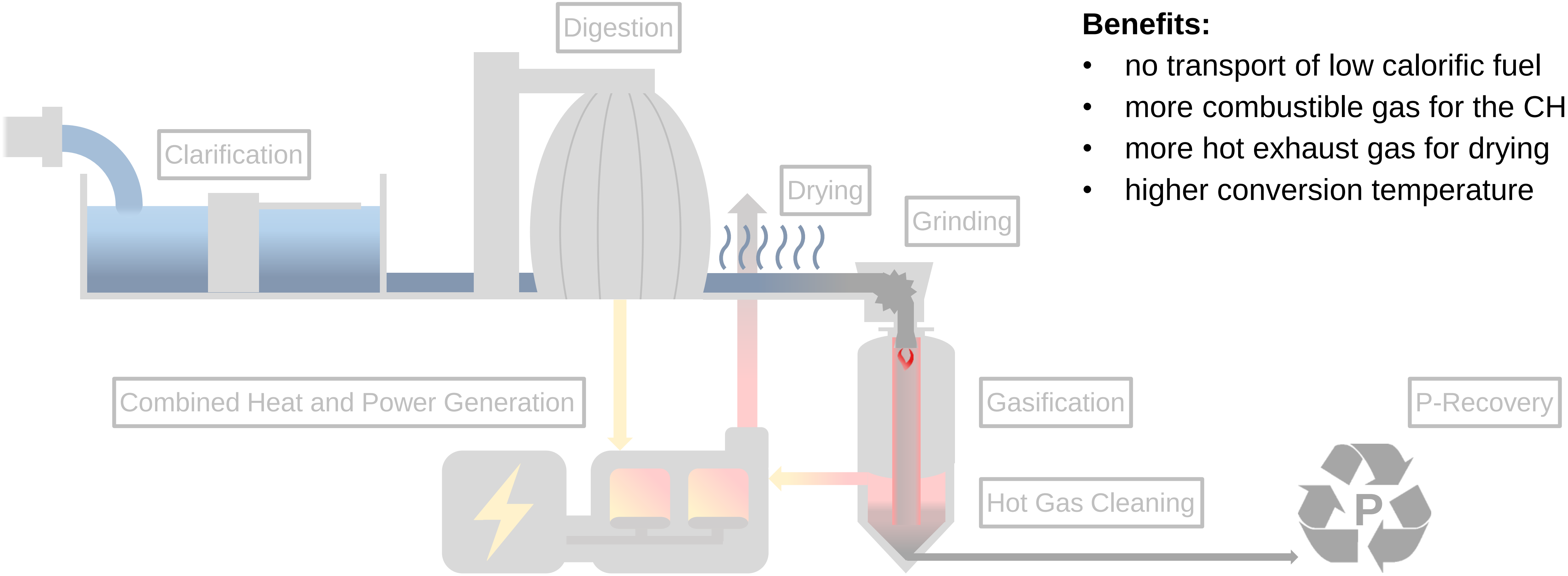
Concept of Sewage Sludge Valorization

Decentralized Entrained Flow Gasification



Benefits:

- no transport of low calorific fuel
- more combustible gas for the CHP unit
- more hot exhaust gas for drying
- higher conversion temperature

Experimental Setup

Baby High Temperature Entrained Flow Reactor (BabiTER)

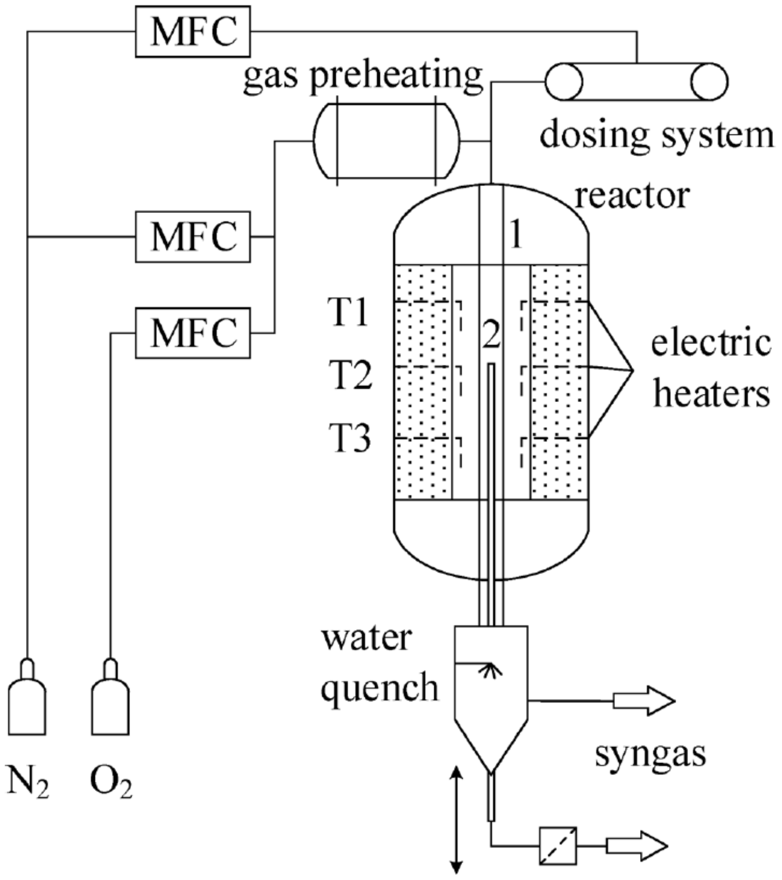
Conversion of the solid fuel to a combustible product gas;
Cracking of organic impurities (pathogens, drug residues, plastics, …);
Release of problematic trace elements.

Technical data:

- Operation mode: electrically heated
- Temperature: up to 1600 °C
- Pressure: atmospheric
- Fuel input: 300 g/h
- Dosing system: gravimetric
- Gasification atmosphere: O_2, N_2

Research focus:

- Residence time in entrained flow gasification
- Influence of the air ratio (0.0 - 1.0) on trace element release
- Influence of 18 additives on trace element release
- Influence of the temperature (800 °C – 1200 °C) on trace element release



Simplified flow sheet of BabiTER

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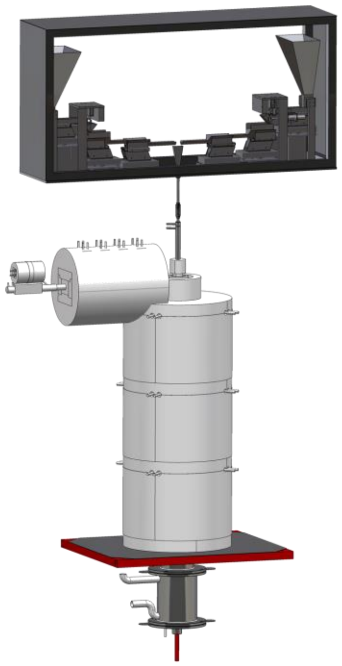
Experimental Setup

Sampling and Methodology



DIN EN ISO 18122 for ash content
DIN 22022-2 via ICP-OES for element content
DIN EN ISO 17294 via ICP-MS for trace element content
DIN 22022-4 via ASS for Hg content

$$C_i = \frac{c_i \cdot x_{\mathrm{Asche},0}}{c_{i,0} \cdot x_{\mathrm{Asche}}}$$

$$X_{\mathrm{ges}} = \frac{1 - x_{\mathrm{Asche},0}/x_{\mathrm{Asche}}}{1 - x_{\mathrm{Asche},0}}$$

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Experimental Results

Influence of the Air Ratio on Trace Element Release

Device	Fuel	Temp. °C	Air Ratio -	Ash %	Pb mg/kg	Pb -	Cd mg/kg	Cd -	Cr mg/kg	Cr -	Cu mg/kg	Cu -	Ni mg/kg	Ni -	Hg mg/kg	Hg -
-	SSS	-	-	41.0	37	100.0%	0.9	100.0%	84	100.0%	354	100.0%	51	100.0%	0.33	100.0%
MO	SSS	850	> 1	100.0	99	110.1%	2.4	106.3%	130	63.2%	920	106.6%	143	114.4%	*0.07*	8.7%
BT	SSS	850	0.0	85.3	65	84.7%	0.4	20.8%	114	64.9%	789	107.2%	100	93.8%	0.11	16.0%
BT	SSS	850	0.2	86.9	57	72.9%	0.3	15.3%	103	57.6%	763	101.7%	92	84.7%	0.09	12.9%
BT	SSS	850	0.4	87.0	53	67.8%	0.3	15.3%	101	56.4%	799	106.4%	92	84.7%	0.09	12.8%
BT	SSS	850	0.6	88.1	54	68.1%	0.3	15.1%	104	57.3%	818	107.6%	99	89.9%	0.10	14.1%
BT	SSS	850	0.8	91.4	55	66.9%	0.3	14.5%	114	60.6%	854	108.2%	103	90.1%	*0.07*	9.5%
BT	SSS	850	1.0	92.6	49	58.8%	0.3	14.4%	104	54.6%	871	109.0%	99	85.6%	0.09	12.1%

MO: Muffle Oven
BT: BabiTer
SSS: Standard Sewage Sludge
Italic: *Value below the detection limit*

Experimental Results

Influence of 18 Additives on Trace Element Release

MO: Muffle Oven
BT: BabiTer
SSS: Standard Sewage Sludge
Italic: *Value below the detection limit*

Device	Fuel	Additive	Temp.	Air Ratio	Ash	Pb		Cd		Cr		Cu		Ni		Hg	
			°C	-	%	mg/kg	-	mg/kg	-	mg/kg	-	mg/kg	-	mg/kg	-	mg/kg	-
-	StSS	-	-	-	41.0	37	100.0%	0.9	100.0%	84	100.0%	354	100.0%	51	100.0%	0.33	100.0%
BT	StSS	-	850	0.4	89.5	44	54.7%	0.3	14.8%	126	68.4%	798	103.3%	112	100.1%	*0.07*	9.7%
BT	StSS	10 % MgO	850	0.4	88.4	42	50.8%	*0.2*	9.6%	109	57.6%	719	90.7%	110	95.8%	*0.07*	9.5%
BT	StSS	10 % Na_2CO_3	850	0.4	83.3	37	47.5%	0.3	15.4%	111	62.3%	762	102.0%	101	93.4%	*0.07*	10.0%
BT	StSS	10 % NH_4Cl	850	0.4	85.4	37	46.4%	*0.2*	10.0%	115	63.0%	733	95.7%	96	86.6%	*0.07*	9.8%
BT	StSS	10 % $MgSO_4$	850	0.4	89.6	38	45.4%	*0.2*	9.5%	105	54.8%	750	93.4%	95	81.7%	*0.07*	9.3%
BT	StSS	10 % $CaCO_3$	850	0.4	91.3	36	42.2%	0.2	9.3%	97	49.7%	743	90.7%	104	87.7%	*0.07*	9.2%
BT	StSS	10 % $FeCl_3$	850	0.4	86.5	33	40.8%	*0.2*	9.9%	113	61.1%	745	96.0%	106	94.3%	*0.07*	9.7%
BT	StSS	10 % $NaHCO_3$	850	0.4	90.2	34	40.3%	*0.2*	9.5%	105	54.4%	789	97.5%	111	94.8%	*0.07*	9.3%
BT	StSS	10 % KF	850	0.4	89.8	32	38.1%	0.2	9.5%	124	64.6%	764	94.9%	109	93.5%	*0.07*	9.3%
BT	StSS	10 % $AlCl_3$	850	0.4	85.3	30	37.6%	*0.2*	10.0%	99	54.3%	704	92.0%	96	86.7%	*0.07*	9.8%
BT	StSS	10 % $CaCl_2$	850	0.4	87.5	31	37.4%	0.3	14.4%	119	62.8%	791	99.6%	104	90.4%	*0.07*	9.4%
BT	StSS	10 % Na_2SO_4	850	0.4	89.3	31	37.1%	*0.2*	9.5%	90	47.1%	738	92.1%	102	87.9%	*0.07*	9.4%
BT	StSS	10 % HCl	850	0.4	86.1	28	34.8%	0.2	9.9%	96	52.1%	762	98.6%	91	81.4%	*0.07*	9.7%
BT	StSS	10 % $MgCl_2$	850	0.4	86.4	29	34.4%	*0.2*	9.5%	112	58.1%	781	96.6%	96	82.1%	*0.07*	9.3%
BT	StSS	10 % $FeCl_2$	850	0.4	88.2	26	30.9%	0.3	14.2%	95	49.3%	723	89.5%	92	78.7%	*0.07*	9.3%
BT	StSS	10 % KCl	850	0.4	88.2	22	26.7%	0.2	9.7%	107	56.7%	707	89.3%	95	82.9%	*0.07*	9.5%
BT	StSS	10 % NaCl	850	0.4	86.7	21	25.9%	*0.2*	9.8%	122	65.8%	731	94.0%	98	87.0%	*0.07*	9.6%
BT	StSS	10 % KBr	850	0.4	84.8	19	24.0%	0.3	15.1%	110	60.7%	646	85.0%	109	99.0%	*0.07*	9.9%
BT	StSS	10 % KI	850	0.4	86.4	12	14.9%	0.3	14.8%	112	60.6%	567	73.2%	110	98.1%	*0.07*	9.7%

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Experimental Results

Influence of the Gasification Temperature on Trace Element Release

Device	Fuel	Temp.	Air Ratio	Ash	Pb		Cd		Cr		Cu		Ni		Hg	
		°C	-	%	mg/kg	-	mg/kg	-	mg/kg	-	mg/kg	-	mg/kg	-	mg/kg	-
-	SSS		-	41.0	37	100.0%	0.9	100.0%	84	100.0%	354	100.0%	51	100.0%	0.33	100.0%
MO	SSS	550	> 1	100.0	98	109.0%	2.4	106.3%	139	67.5%	910	105.4%	130	104.0%	*0.07*	8.7%
BT	SSS	800	0.3	84.1	58	76.1%	0.4	21.1%	125	72.4%	732	100.9%	95	90.5%	0.10	14.8%
BT	SSS	900	0.3	89.3	44	55.3%	*0.2*	9.9%	132	71.8%	796	103.3%	95	85.3%	0.12	16.7%
BT	SSS	1000	0.3	92.3	20	23.5%	*0.2*	9.6%	178	93.7%	833	104.5%	110	95.4%	0.12	16.1%
BT	SSS	1100	0.3	94.4	11	13.1%	*0.2*	9.4%	173	88.9%	939	115.2%	102	86.3%	*0.07*	9.2%
BT	SSS	1200	0.3	96.2	9	10.4%	*0.2*	9.2%	108	54.5%	900	108.4%	120	99.8%	*0.07*	9.0%

MO: Muffle Oven
BT: BabiTer
SSS: Standard Sewage Sludge
Italic: *Value below the detection limit*

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Experimental Results

Influence of the Gasification Temperature and Additives on Iron Heavy Sewage Sludge on Trace Element Release

Device	Fuel	Additive	Temp. °C	Air Ratio -	Ash %	Pb mg/kg	Pb -	Cd mg/kg	Cd -	Cr mg/kg	Cr -	Cu mg/kg	Cu -	Ni mg/kg	Ni -	Hg mg/kg	Hg -
-	FeSS	-	-	-	37.07	47.5	100.0%	1.15	100.0%	59.5	100.0%	320	100.0%	37.5	100.0%	0.39	100.0%
MO	FeSS	-	850	> 1	100.00	113	88.2%	3.2	103.2%	68	42.4%	840	97.3%	94	92.9%	*0.07*	6.7%
BT	FeSS	-	850	0.4	92.29	57	48.2%	0.9	31.4%	121	81.7%	807	101.3%	104	111.4%	*0.07*	7.2%
BT	FeSS	-	1100	0.4	96.59	28	22.6%	0.5	16.7%	77	49.7%	837	100.4%	91	93.1%	*0.07*	6.9%
BT	FeSS	10 % NaCl	850	0.4	87.96	42	35.9%	0.8	28.2%	104	70.9%	738	93.5%	88	95.2%	*0.07*	7.3%
BT	FeSS	10 % KCl	850	0.4	92.01	38	31.0%	1	33.7%	89	58.0%	689	83.5%	84	86.8%	*0.07*	7.0%

Device	Fuel	Additive	Temp. °C	Air Ratio -	Ash %	As mg/kg	As -	Tl mg/kg	Tl -	Zn mg/kg	Zn -
-	FeSS	-	-	-	37.07	4.2	100.0%	0.2	100.0%	940	100.0%
MO	FeSS	-	850	> 1	100.00	10	88.3%	*0.2*	37.1%	2490	98.2%
BT	FeSS	-	850	0.4	92.29	6.3	60.3%	*0.2*	40.2%	1760	75.2%
BT	FeSS	-	1100	0.4	96.59	5.5	50.3%	*0.2*	38.4%	591	24.1%
BT	FeSS	10 % NaCl	850	0.4	87.96	6	57.9%	0.2	40.5%	1420	61.3%
BT	FeSS	10 % KCl	850	0.4	92.01	5.9	54.5%	0.2	38.8%	1450	59.8%

MO: Muffle Oven
BT: BabiTer
FeSS: High Iron Sewage Sludge
Italic: Value below the detection limit

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Experimental Results

Influence of the Gasification Temp. and Additives on Aluminum Heavy Sewage Sludge on Trace Element Release

Device	Fuel	Additive	Temp. °C	Air Ratio -	Ash %	Pb mg/kg	Pb -	Cd mg/kg	Cd -	Cr mg/kg	Cr -	Cu mg/kg	Cu -	Ni mg/kg	Ni -	Hg mg/kg	Hg -
-	AlSS	-	-	-	39.39	27	100.0%	1.1	100.0%	82	100.0%	342	100.0%	51	100.0%	0.15	100.0%
MO	AlSS	-	850	> 1	100.00	160	233.4%	2.9	103.8%	56	26.9%	909	104.7%	112	86.5%	*0.07*	18.4%
BT	AlSS	-	850	0.4	83.72	53	92.4%	0.6	25.7%	90	51.6%	870	119.7%	84	77.5%	*0.07*	22.0%
BT	AlSS	-	1100	0.4	92.31	12	19.0%	0.2	7.8%	85	44.2%	940	117.3%	93	77.8%	*0.07*	19.9%
BT	AlSS	10 % NaCl	850	0.4	83.79	23	38.5%	0.3	12.3%	72	39.7%	776	102.6%	88	78.1%	*0.07*	21.1%
BT	AlSS	10 % KCl	850	0.4	85.39	18	29.6%	0.2	8.1%	69	37.4%	718	93.2%	93	80.9%	*0.07*	20.7%

Device	Fuel	Additive	Temp. °C	Air Ratio -	Ash %	As mg/kg	As -	Tl mg/kg	Tl -	Zn mg/kg	Zn -
-	AlSS	-	-	-	39.39	5.0	100.0%	0.2	100.0%	1060	100.0%
MO	AlSS	-	850	> 1	100.00	10.0	78.8%	*0.2*	39.4%	2930	108.9%
BT	AlSS	-	850	0.4	83.72	7.7	72.5%	0.4	94.1%	2170	96.3%
BT	AlSS	-	1100	0.4	92.31	8.1	69.1%	0.2	42.7%	514	20.7%
BT	AlSS	10 % NaCl	850	0.4	83.79	6.5	58.8%	*0.2*	45.2%	1620	69.1%
BT	AlSS	10 % KCl	850	0.4	85.39	7.1	63.0%	*0.2*	44.4%	1420	59.5%

MO: Muffle Oven
BT: BabiTer
AlSS: High Aluminum Sewage Sludge
Italic: Value below the detection limit

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Conclusions

Summary of Results and Outlook

Release in muffle oven:

Clear reduction of Hg and Tl. Moderate reduction of As and Cr. No reduction of Pb, Cd, Cu, Ni and Zn.

Release in gasification:

Clear reduction of **Cd**, Hg and Tl. Moderate reduction of **Pb**, **Zn**, As and Cr. No reduction of Cu and Ni.
The influence of the air ratio is neglectable.
The influence of additives can be useful, but side effects (costs, corrosion) must be taken into account.
The influence of temperature is dominant, but the gasification system must allow a stable operation.

Outlook:

We tested sewage sludge in a 100 kW (30 kg/h) entrained flow gasifier with water quench:

- We see the expected reduction of trace elements in the main ash stream.
- The filter dust contains very high concentrations of trace elements.
- We tested KCl as an additive. The trace element concentration in the main ash stream was higher than before.

→ **Hot gas cleaning to benefit from the release of trace elements for phosphorus recovery.**

Thank you
for your attention.

Don't hesitate
to ask questions!

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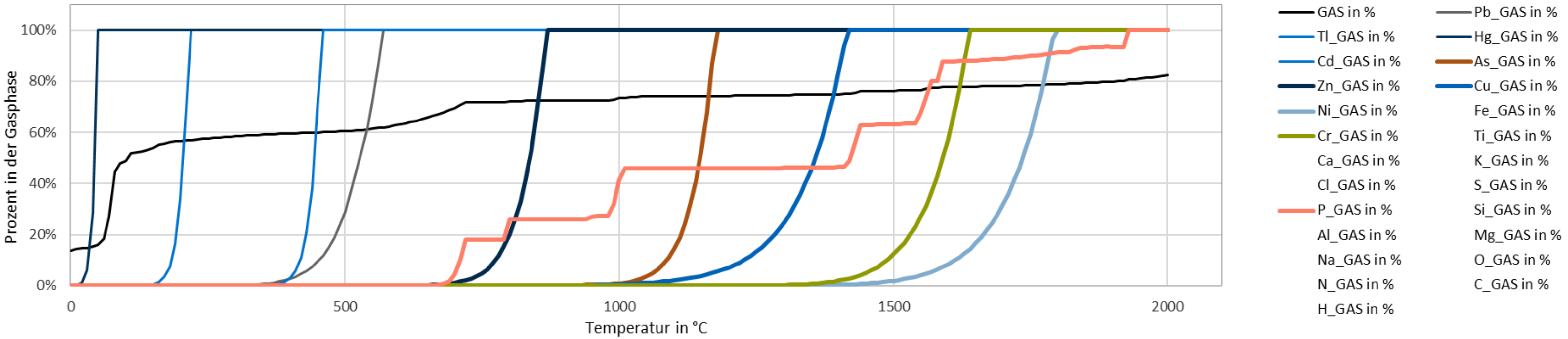
Backup

Equilibrium consideration in FactSage

Sewage Sludge Composition + Gas Atmosphere + Additive

C	H	N	S	Cl	O	Na	Mg	Al	Si	P	S	K	Ca	Ti	Fe	Cr	Zn	As	Cd	Hg	Pb	Tl	Ni	Cu
30	5	5	1	0.3	58.7	0.7	1.4	5.2	12.1	7.3	1.5	0.9	8	0.4	9.9	0.03	0.4	0.004	0.0006	0.0001	0.015	0.0001	0.4	0.0916

FactSage™



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Backup

Equilibrium consideration in FactSage to examine air ratio and additives