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UNIVERSITY OF CHEMISTRY AND TECHNOLOGY PRAGUE

Complex characteristics of char from dry stabilized sewage sludge pyrolysis

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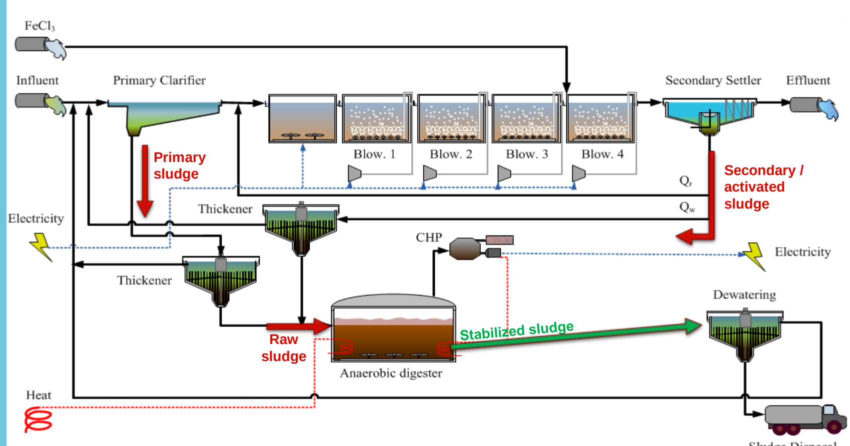
Sewage sludge production



Picture reference: Conaqua -Online: http://www.conaqua.es/estudio-de-simulacion-sobre-la-recuperacion-de-p-en-la-edar-sur-de-madrid/ (accessed 31.05.2018)

Sewage sludge disposal in Germany

Year		2010	2011	2012	2013	2014	2015	2016
Sludge disposal		tonnes of dry matter						
material recycling	in agriculture	566295	567187	541935	484464	470882	427736	423497
	in landscaping measures[1]	259312	254402	235439	203712	216148	190127	169439
	other material recycling[2]	58052	61106	58107	60692	35386	33547	31064
	sum	*883659*	*882695*	*835481*	*748868*	*722416*	*651410*	*624000*
thermal disposal	mono-incineration	*1003749*	*1067431*	*1008830*	230581	425108	432516	460411
	co-incineration				250326	400115	446871	615928
	unknown				553864	252707	269292	66554
	sum				*1034771*	*1077930*	*1148679*	*1142893*
other direct disposal[3]		-	-	-	4232	2642	2998	6293
sum total		1887408	1950126	1844311	1787871	1802988	1803087	1773186

Year		2010	2011	2012	2013	2014	2015	2016
Sludge disposal		% of total sludge disposed						
material recycling	in agriculture	30	29	29	27	26	24	24
	in landscaping measures	14	13	13	11	12	11	10
	other material recycling	3.1	3.1	3.2	3.4	2.0	1.9	1.8
	sum	*47*	*45*	*45*	*42*	*40*	*36*	*35*
thermal disposal	mono-incineration	*53*	*55*	*55*	13	24	24	26
	co-incineration				14	22	25	35
	unknown				31	14	15	4
	sum				*58*	*60*	*64*	*64*
other direct disposal		-	-	-	0.24	0.15	0.17	0.35
sum total		100	100	100	100	100	100	100

[1] For instance recultivation, composting.

[2] For instance building materials, solification, fermentation.

[3] This includes quantities transferred to drying plants where the further disposal is unknown.

The Federal Statistical Office. Environmental surveys; Water supply industry; Waste water disposal - sewage sludge. Online: https://www.destatis.de/EN/FactsFigures/NationalEconomyEnvironment/Environment/EnvironmentalSurveys/WaterSupplyIndustry/Tables/TableWastWaterDisposalSewageSludge.html (accessed 21.5.2018)

Issues of the sludge disposal

Motivation for the change of the sludge utilization:

- ban on sewage sludge landfilling
- sufficient hygienization of the sludge
  - to lower the levels of pathogens under legislation limits and to prevent their repeated increase above the limits
- destruction of microorganic pollutants – POPs, PPCPs
- material and energy utilization of the sludge

Impact of the motivation in Germany:

- ✓ New sewage sludge ordinance (in force since 03.10.2017):
  - ‘sustainable and safe utilization of phosphorus by recovering phosphorus, especially from municipal sewage sludge’
  - ‘in 12 respectively 15 years the agricultural and landscaping use of sewage sludge from treatment plants over 100.000 respectively 50.000 PT is forbidden’
    - ‘phosphorus from this sludge has to be recovered if its content is over 2 %’ and it ‘can be recovered directly from the sludge (at least 50 %) or after its thermic use’ – ‘at least 80 % of the phosphorus in the ashes has to be recovered’

Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (Germany). Case Study // SDG 6. Online: http://www.unece.org/fileadmin/DAM/RCM_Website/SDG_6_Additional_Case_Study2.pdf (accessed 22. 05. 2018).

Sewage sludge disposal in the Czech Republic

Year	2010	2011	2012	2013	2014	2015	2016	2017
Sludge disposal	tonnes of dry matter							
agricultural use	60639	61750	51912	54713	47830	63061	62551	75451
composting	45528	45985	53222	50384	60511	67065	65163	60930
landfilling	6177	9527	9340	7123	5236	6513	10183	11809
incinerating	3336	3538	3528	3232	3400	2167	4814	4736
other[1]	55009	43018	50188	38822	42185	34191	30998	25151
sum total	*170689*	*163818*	*168190*	*154274*	*159162*	*172997*	*173709*	*178077*

Year	2010	2011	2012	2013	2014	2015	2016	2017
Sludge disposal	% of total sludge disposed							
agricultural use	36	38	31	35	30	36	36	42
composting	27	28	32	33	38	39	38	34
landfilling	3.6	5.8	5.6	4.6	3.3	3.8	5.9	6.6
incinerating	2.0	2.2	2.1	2.1	2.1	1.3	2.8	2.7
other[1]	32	26	30	25	27	20	18	14
sum total	*100*	*100*	*100*	*100*	*100*	*100*	*100*	*100*

[1] For instance technical landfill layer

Czech Statistical Office. Water Supply Systems, Sewerage and Watercourses - 2010-2017. Online: https://www.czso.cz/csu/czso/water-supply-systems-sewerage-and-watercourses-2017 (accessed 05.06.2018)

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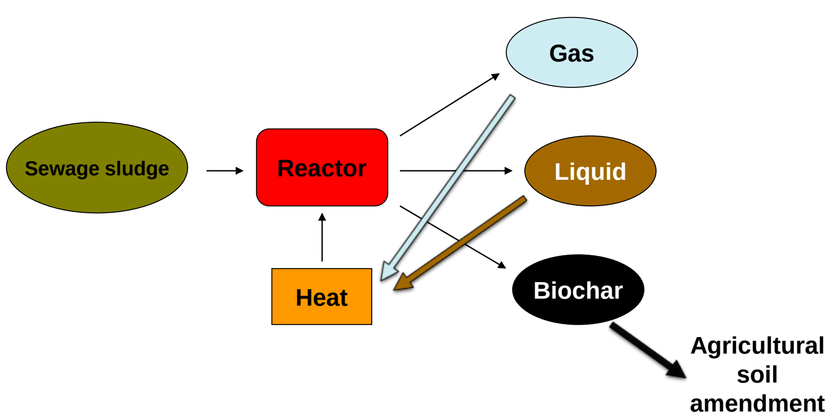
Pyrolysis

- a thermal decomposition of organic material at elevated temperatures in the oxygen-free environment



Bridgwater A.V., Review of Fast Pyrolysis of Biomass and Product Upgrading. Biomass and Bioenergy 38 (2012) 68-94. (Adjusted by Skoblia, Pohořelý, Moško – UCT)

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Impact of sludge-derived biochar use on soil

It increases soil fertility:

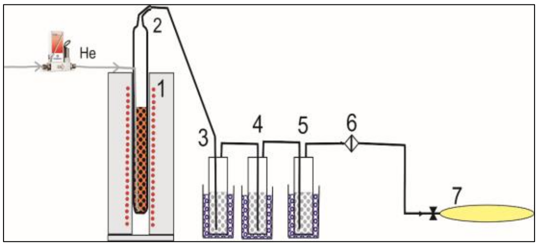
- Increases water retention
- Prevents leaching of nutrients (N, P, K) from fertilizers to groundwater
- Loosens/aerates the soil
- Sequestrates carbon dioxide (C form)
- Partially substitutes compound fertilizers due to relatively high content of biogenic elements
- Partially substitutes calcium based soil amendments due to relatively high content of calcium

Sludge-derived biochar advantages over the sludge

Sludge-derived biochar is stable porous material with high content of nutritious elements (P 5–8 wt. %, N 1–5 wt. %)

- Increases water retention
- Prevents leaching of nutrients (N, P, K)
- Heavy metals are immobilized - their mobility=solubility is limited
- Organic pollutants are destroyed during pyrolysis
- Decreases greenhouse gas emissions (CH_4, N_2O)

Experimental campaign



1 – oven, 2 – quartz reactor,
3 – 5 ice-cooled impingers,
6 - porous filter,
7 – tedlar bag

Inert carrier gas: helium
Pyrolysis temperature: 400-800 °C

After pyrolysis

Before pyrolysis

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Sewage sludge for experiments

Stabilized sewage sludge from municipal wastewater treatment plant (with mesophilic anaerobic stabilization of the sludge) in the Czech Republic.

Proximate analysis		
Ash, A^d	wt. %	43.3
Volatiles, V^{daf}	wt. %	86.8
Fixed Carbon, FC^{daf}	wt. %	13.2
Calorific values		
Higher Heating Value, HHV^d	MJ kg^{-1}	12.7
Lower Heating Value, LHV^d	MJ kg^{-1}	11.8
Ultimate analysis		
C^d	wt. %	28.8
H^d	wt. %	4.20
N^d	wt. %	4.22
O^d	wt. %	18.4
S^d	wt. %	1.10
Cl^d	mg kg^{-1}	433
F^d	mg kg^{-1}	255

The sludge ash composition determined by XRF analysis

Species	wt. %
Al_2O_3	16.0
CaO	14.0
Fe_2O_3	13.9
K_2O	1.64
MgO	2.64
P_2O_5	18.2
SiO_2	28.5
Sum	94.9

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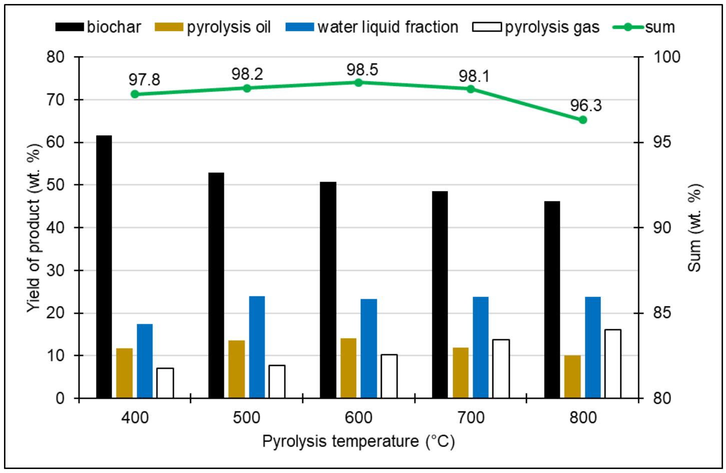
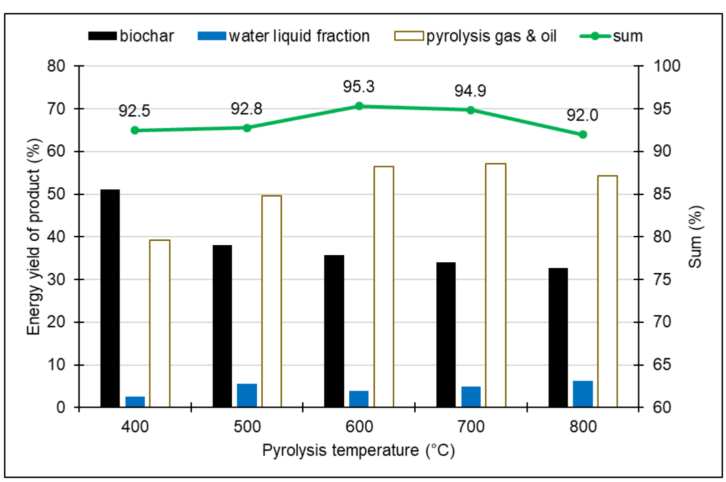
Mass balance



Energy balance



Sludge-derived biochar

Property	Symbol	Unit	Pyrolysis temperature				
			400	500	600	700	800
Ash content	A^d	wt %	67.9	72.7	75.8	77.8	80.8
Volatiles content	V^d	wt %	21.5	15.9	11.7	5.93	0.922
Carbon content	C^d	wt %	23.1	21.4	20.5	19.3	17.2
Hydrogen content	H^d	wt %	1.62	1.04	0.716	0.497	0.310
Nitrogen content	N^d	wt %	3.04	2.66	2.26	1.55	0.939
Sulphur content	S^d	wt %	0.760	0.810	0.770	0.850	0.840
Higher Heating Value	HHV^d	MJ kg^{-1}	9.49	8.23	8.04	8.01	8.10
Lower Heating Value	LHV^d	MJ kg^{-1}	9.14	8.01	7.89	7.90	8.03
pH	pH_{H2O}	-	7.09	7.40	9.14	11.8	10.8
Loose poured bulk density	ρ_L	kg m^{-3}	771	777	756	767	750
Apparent density #	ρ_{Hg}	kg m^{-3}	1348	1290	1281	1273	1205
True solid density ##	ρ_{He}	kg m^{-3}	2123	2268	2359	2480	2581
Porosity ###	ε	-	0.37	0.43	0.46	0.49	0.53
Specific surface area ‡	S_{BET}	m^2 g^{-1}	15	50	55	60	86
Specific surface area of mesopores ‡‡	S_{meso}	m^2 g^{-1}	11	23	24	26	49
Total pore volume ‡‡‡	V_{tot}	mm^3_{liq} g^{-1}	66	101	103	105	121
Micropores volume ‡‡	V_{micro}	mm^3_{liq} g^{-1}	1.9	13	16	18	18

density determined by Mercury porosimetry

density determined by Helium porosimetry

$\varepsilon = 1 - (\rho_{Hg} - \rho_{He})$

volume determined by Mercury porosimetry

‡ - determined from adsorption isotherm of N_2 at T=77 K

‡‡ - determined by t-plot method

‡‡‡ - determined from adsorption isotherm of N_2 at P/P_0 = 0,99

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Conclusions

- Sludge pyrolysis technologies are available.
- Production of sludge-derived biochar for agricultural use is suitable for wastewater treatment plants with anaerobic stabilization of the sludge and with low heavy metals content of the sludge.

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