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Evaluation of Sewage Sludge Co-incineration in the Existing Heating Plant or Power Plant from Emission Production Point of View

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Sewage sludge from wastewater treatment consists of inorganic elements (eg. nitrogen, phosphorus, potassium, calcium and magnesium) and organic elements. Up-to-date technologies allow a number of ways of sewage sludge treatment. Inorganic elements are good fertilizers and organic elements are used for regeneration of land – these are excellent features for fertilizing. But sewage sludge also contains large amounts of pollutants (e.g. heavy metals) which can contaminate agricultural land. This is the reason, why utilization for agricultural purposes is not allowed in several European countries and therefore other methods are preferred.
These are landfilling, energy recovery (incineration, anaerobic digestion, pyrolysis, etc.) or mechanical and biological modifications to minimize the environmental impact. Incineration is an advantageous way of energy recovery. This process utilizes calorific value of sewage sludge and also minimizes the environmental impact. There are more options – incineration in new incineration units specialized on sewage sludge or co-incineration with another primary fuel (e.g. co-incineration with coal in heating or power plants).
The objective of the paper is to create models (new sewage sludge incinerator and coal-fired power plant, where is incineration sludge with coal) to detection amount of emissions. Emissions are compared with European emission limits for waste incineration plants. The goal of the research is evaluation of the two mentioned ways of sewage sludge incineration from emission production point of view. Results are then compared with European limits on emissions from waste-to-energy plants. Further, modifications in flue gas cleaning system are proposed to meet the limits and costs on these modifications are performed.

1. Sewage sludge disposal in the European countries

Sewage sludge from waste water treatment is one of main part of waste management in the world. Production of sewage sludge is about 10,000 kt/y in the European Union (EU). Incineration of Sewage sludge is one of possible ways to minimize the environmental impact. Sewage sludge disposal is shown in Figure 1. The bar chart in Figure 1 was obtained using data from Eurostat. The incineration represents average 11 % of disposal in the EU (Eurostat). The other possible way of sewage sludge energy utilization are gasification (e.g. Seggiani, 2013), pyrolisys (e.g. De Filippis, 2013), digestion (e.g. Elsäßer, 2012) or co-incineration at cement manufacturing (e.g. Aranda Usón, 2012).

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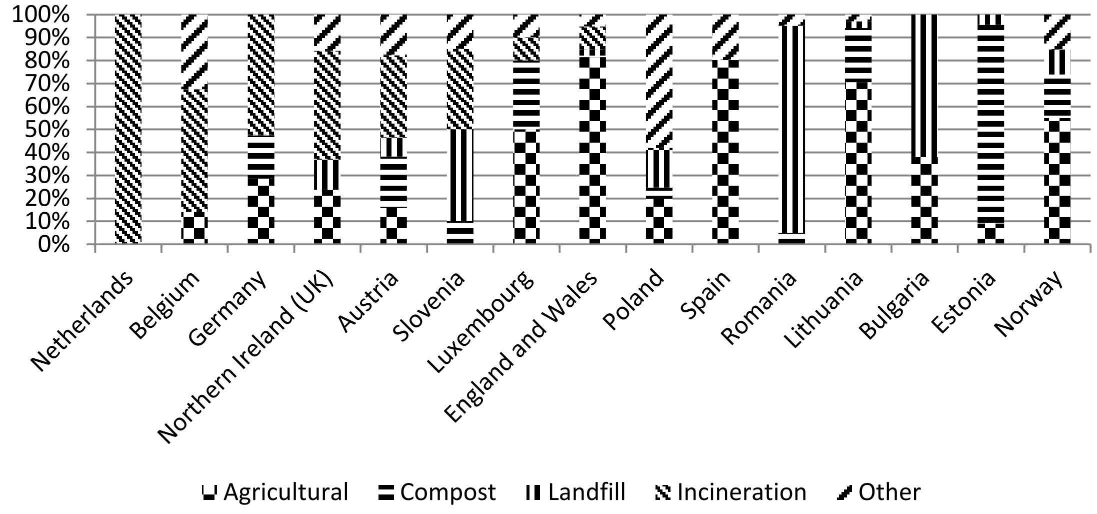

Figure 1: Disposal of sewage sludge in European countries

2. Input parameters for calculation

Calculation considers anaerobic stabilized sewage sludge with volatile substances content 40 %wt in dry solids. Ultimate analyses of sewage sludge from many places in the world are shown in Elsäßer (2013). Other considered fuels are coal and municipal solid waste (MSW). The emissions production and energy productions were calculated considering five different technologies:

- Mono-incineration sludge (Layout 1)
- Co-incineration sludge with coal in one combustion chamber (sludge:coal = 1:10, Layout 2)
- Co-incineration sludge with coal in one combustion chamber (sludge:coa l= 1:1, Layout 3)
- Co-incineration sludge with waste in one combustion chamber (maximum steam power production is 42 t/h, Layout 4)
- Sludge combustion within the coal-fired plant in a different combustion chamber for each fuel and common electrical power production system (sludge:coal = 1:10, Layout 5)

Table 1: Fuel parameters used in computation

			Sewage sludge	Coal	Municipal solid waste
Composition of Fuel	Combustibles	[%wt]	23	61	43
	Water	[%wt]	35	29	22
	Ash	[%wt]	42	10	35
Composition of Combustibles	C	[%wt]	73.91	73.28	60.27
	H	[%wt]	5.90	5.74	6.51
	N	[%wt]	0.71	0.82	8.3
	O	[%wt]	17.95	18.52	24.82
	S	[%wt]	1.54	1.64	0.05
	Cl	[%wt]	0	0	0.05
Lower heating value		[MJ/kg]	5.98	17.16	10.53

Lower heating value is computed by IGT equation presented at Bransby (1991). The power production calculation reflects applies these constants: Losses due to incomplete combustion is 1 % of produced heat energy from fuel and losses due to radiation, convection and conduction is 0.56 MW. Outlet steam pressure from a turbine is 10 bar for layout 1, layout 4 and layout 5. Outlet steam pressure from a turbine for layout 2 and layout 3 is 0.2 bar. Steam at the outlet from a turbine (pressure 10 bar) is useful for drying sewage sludge and central heating of nearby buildings. Steam outlet from turbine at pressure 0.2 bar represents maximal electricity production in coal power plants. All computation reflects European Directives and Reference Document on the Best Available Techniques for Waste Incineration (European IPPC Bureau 2003 and 2005).

2.1 Mono-incineration of sludge (Layout 1)
Mass flow of dry solid of sewage sludge is 100 t/d. Analyses of the fuels are summarized in Table 1. This layout considered only sewage sludge incineration and additional fuel may be used in exceptional cases (e.g. startup and shutdown technology). The flow rate of natural gas is 10 m_N^3/h and its lower heating value is 35.6 MJ/m_N^3. The technological diagram is shown in Figure 2.

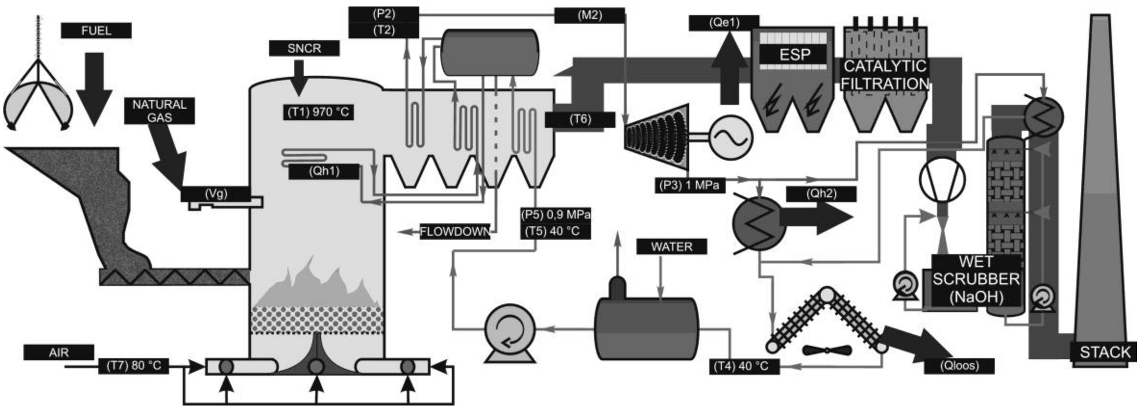

Figure 2: Diagram of sewage sludge mono-incineration and co-incineration (layout 1-3)

Advantages: Advantages of this technology are smaller flow rate of flue gas than in case of a technology with co-incineration (sludge-coal) which causes lower costs of flue gas cleaning system. This type of technology (mono-incineration) is usually built in a wastewater treatment area. It results in smaller costs of sludge transport and in incineration of biogas from anaerobic stabilization to improve boiler efficiency and primary saving of natural gas. Other important advantage is utilization of heat produced after a turbine for sewage sludge drying or technology heating in a waste water treatment process.
Disadvantages: It's necessary to build new facility at a waste water treatment area for maximum technology efficiency. It is usually difficult due a public negative attitude to live nearby these units. Other problem is to find free and suitable area to build a technology for sewage sludge incineration.

2.2 Co-incineration of sludge with coal in one combustion chamber (sludge:coal=1:10, Layout 2)
Second layout represents incineration of sewage sludge in a coal plant. Mass flow of fuel is 90 % of coal and 10 % of sewage sludge. Mass flow of dry solid of sewage sludge is 100 t/d as for the first layout. Ultimate analyses of fuels (sewage sludge and coal) are summarized in Table 1. Natural gas mass flow is negligible because it is expected that sewage sludge is incinerated with coal in sufficient combustion conditions (e.g. temperature in combustion chamber will above than 900 °C).
Advantages: This layout uses existing technology (combustion chamber, boiler and water management with power production unit) and transport infrastructure for sewage sludge transport. Co-incineration of sewage sludge provides savings of primary fuel (about 2.3 t/h of coal). Next advantage is possibility of residual heat from coal combustion utilization for sludge drying.
Disadvantages: Coal plants usually have flue gas cleaning systems to minimize only particles and SO_2 emissions. Fundamental improvements of flue gas cleaning system are necessary to reduce other pollutant emissions (e.g. PCDD/F, heavy metals or NO_x emissions). This is quite problematic and expensive because flow rate of flue gas is very high.

2.3 Co-incineration of sludge with coal in one combustion chamber (sludge:coal = 1:1, Layout 3)
This technology is modification of the first layout. Co-incineration of sludge with coal improved the performance and allowed to incinerate sewage sludge with higher water content.

2.4 Co-incineration of sludge with waste in one combustion chamber (Layout 4)
Next possibility of co-incineration is incineration of sludge in a waste to energy plant (WtE) displayed on Figure 3. Considered waste throughput limit is 12 t/h therefore incineration of sewage sludge decreases amount of incinerated waste. The waste ultimate analyse is summarized in Table 1. Co-incineration with waste is good option because waste to energy plants usually has highly efficient flue gas cleaning systems for sufficient sewage sludge incineration emissions treatment.

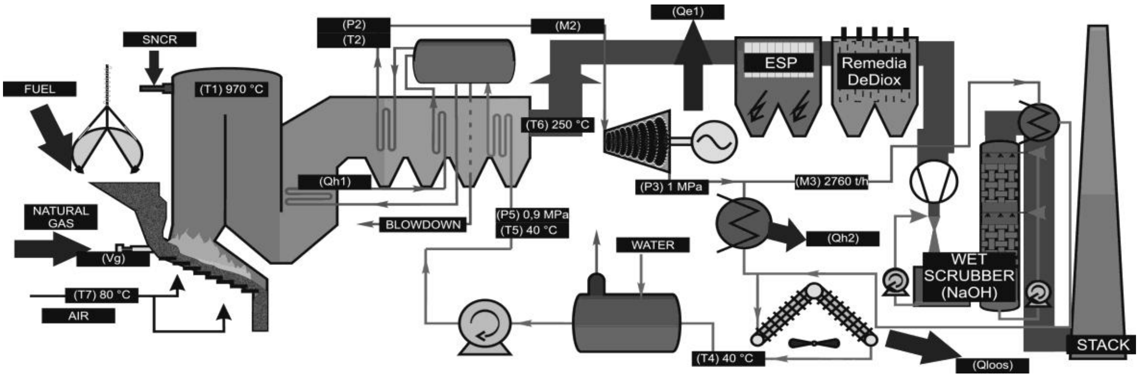

Figure 3: Diagram of sewage sludge co-incineration with waste

Advantages: Minimal investment costs for combustion technology and flue gas cleaning system modification.
Disadvantages: This layout is not desirable. Primary purpose of WtE plants is municipal solid waste treating. Waste to energy plant must respect throughput limit and therefore incineration of sludge decreases total amount of incinerated waste.

2.5 Sludge combustion in a coal-fired plant with individual combustion chamber for each fuel (Layout 5)

The last option is new sewage sludge combustor in a coal-fired plant (Figure 4). The mass flow rate of fuel is the same as in case of layout 2 (dry solid of sewage sludge is 100 t/d and mass flow of coal is 57,700 kg/h). Advantage of this technology is possibility of produced steam utilization in existing power production system (steam turbine and feed water treatment).

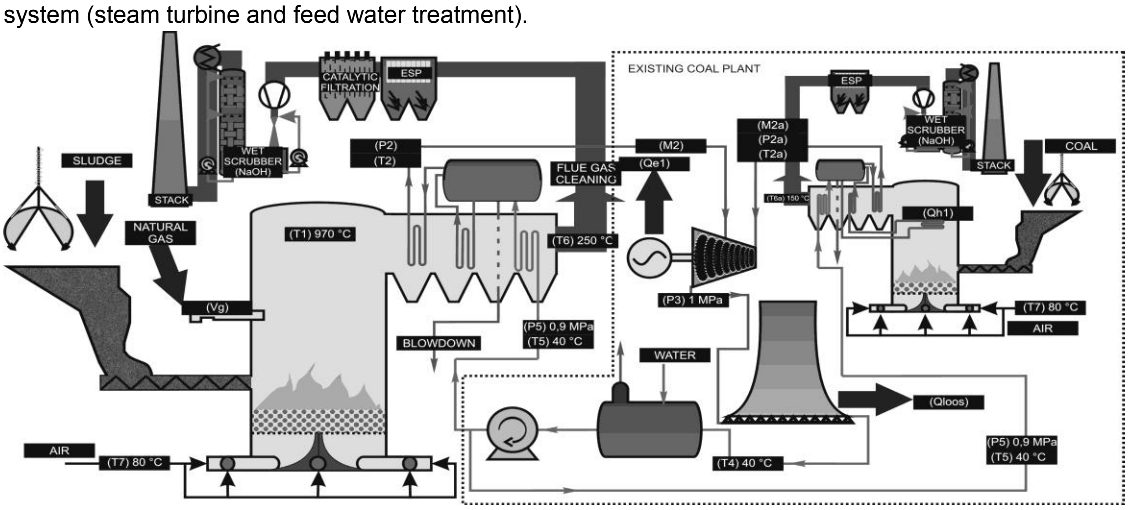

Figure 4: Diagram of sewage sludge incineration in the existing coal plant area

3. Evaluation of considered alternatives

The input constants for all calculation models are shown in Table 2. Flue gas compositions (without polluting substances) presented in Table 3 was computed using ideal stoichiometric calculations. The temperature in combustion chamber (970 °C) was set by air excess and heat absorption rates in combustion chamber. Information about flue gas composition allows steam flow rate and power production calculation for each layout.

Table 2: Input parameters and output values of computation of Layout 1-5 power production

		Unit	L1	L2	L3	L4	L5
Secondary fuel flow rate (natural gas)	(Vg)	[m_N^3/h]	10	0	10	10.00	0
air excess	(α)	[-]	2.04	1.82	2.47	1.98	1.60
Steam flow rate	(M2)	[kg/h]	9,189	27,5811	38,217	41,792	9,189
Steam flow rate	(M2a)	[kg/h]	-	-	-	-	278,699
Steam pressure	(P2)	[MPa]	4.0	17.5	4.0	4.0	4.0
Steam pressure	(P2a)	[MPa]	-	-	-	-	17.5
Steam temperature	(T2)	[°C]	400	540	400	400	540
Flue gas temperature	(T3)	[°C]	250	150	250	250	150
Isoentropic efficiency of turbine		[-]	0.70	0.85	0.70	0.75	0.85
Electric power production related to 1t of dry sludge	(Qe1)	[MW/t dry sludge]	0.056	0.270	0.059	0.067	0.272
Useful heat production related to 1t of dry sludge (steam 1MPa, 255°C)	(Qh2)	[GJ/(h*t dry sludge)]	2.594	0.000	10.790	11.726	0.000

Table 3: Compositions of flue gas at output from heat recovery steam generator

Composition of flue gas		L1	L2	L3	L4	L5
O_2	[% vol]	9.19	8.63	11.47	9.21	8.63
CO_2	[% vol]	7.68	9.25	6.84	8.12	9.25
N_2	[% vol]	67.08	71.45	71.77	69.63	71.45
Ar	[% vol]	0.82	0.87	0.87	0.84	0.87
SO_2	[% vol]	0.06	0.08	0.06	0.02	0.08
HCl	[% vol]	0.00	0.00	0.00	0.00	0.00
H_2O	[% vol]	15.17	9.73	8.99	12.18	9.72

Calculation of emissions production was performed using data from Chang (2008). These data corresponds to amount of dry solid of sewage sludge and according to oxygen volume in flue gas. Estimated values of emissions are presented in Table 5 and proposed flue gas cleaning measures for emission limits fulfillment are showed in Table 4 (Klemeš et al., 2010).

Table 4: Comparison of proposed flue gas cleaning measures for each layout with and without sludge co-combustion

Flue gas cleaning changes	L1	L2	L3	L4	L5
without sludge combustion	-	ESP, WS	-	SNCR, ESP, CF, WS	ESP, WS
with sludge combustion	ESP, CF, WS	ESP, CF, WS	ESP, CF, WS	SNCR, ESP, CF, WS	ESP, CF, WS
SNCR: Selective Non-catalytic reduction, ESP: Electrostatic precipitator, CF: Catalytic filtration, WS: Wet scrubber (NaOH)					

Table 5: Comparison of emission values from incineration or stack emission and emission limit values

Polluting Substances	Emission limit values (2010/75/EU) [mg/m_N^3]	Combustion outlet L1, L5	L2	L3	L4	Stack emissions L1, L5	L2	L3	L4
HCl	10	0.00	0.00	0.00	27.43	0.00	0.00	0.00	0.41
HF	2	4.20	0.21	1.03	7.72	0.34	0.02	0.08	0.62
SO_2	50	1,708.50	2,203.17	1,600.32	521.91	34.17	44.06	32.01	10.44
NO_2	200	176.71	9.04	43.56	572.25	44.18	2.26	10.89	143.06
Cd a Tl *	Σ0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
Hg *	0.05	2.96	0.15	0.73	0.85	0.03	0.00	0.01	0.01
Sb, As, Pb, Cr, Co, Cu, Ni, Mn, V *	Σ0.5	1.60	0.08	0.39	0.46	0.26	0.01	0.06	0.07
Dioxins and furans ** [ngTEQ/m_N^3]	0.1	2.64	0.14	0.50	4.09	0.42	0.02	0.08	0.65

* Average emission limit values over a sampling period (minimum of 30 min and a maximum of 8 h)

** Average emission limit value over a sampling period (minimum of 6 h and a maximum of 8 h)

4. Conclusions

Co-incineration of sewage sludge is one of the available ways to anaerobic stabilized sewage sludge utilization for energy production and to minimize its volume for landfilling at the same time.
The aim of this paper was to evaluate sewage sludge incineration process parameters in the existing coal-fired power plant. It is not possible without significant changes in technology flue gas cleaning system. These results correspond with measurement by Kutil (2004), who tested this option in the existing unit (coal-fired plant). The main problems are emissions of PCDD/F and heavy metals (especially Hg). Calculations also showed SO_2 emissions problem, but most of the existing plants use efficient technologies for SO_2 reduction.
The bigger advantage of co-incineration of sludge with coal in existing plant is use of the existing combustor technology and the transport infrastructure. Other advantage is savings of primary fuel. Anaerobic stabilized sewage sludge, with content of 40 %wt of volatile substances in dry solids (100 t/d) and 40 %wt of water saves about 2.3 t/h coal.
Other option of co-incineration is sludge incineration in a WtE plant. This layout does not need large investments in flue gas cleaning technology. However, it is not desirable option because capacities of WtE plants are fully exploited in Eastern Europe and therefore the sludge co-incineration in WtE plants it is not desirable since it decreases amount of incinerated waste.

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