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Analysis of Requirement for Sewage Sludge Incineration

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Municipal wastewater treatment plants have produced about 160,000 t/y to 210,000 t /y (Eurostat, 2014) of raw sludge (expressed as dry ratio) in the Czech Republic. Considering the calorific value of the dry sludge is about 15 GJ/t, it represents the caloric content in the raw sludge of about 3,000 GJ/y. In many cases, the processing of the separated raw sludge includes the process of anaerobic fermentation, which generates biogas for energy utilization. In the Czech Republic, the produced sludge, mainly digested and dewatered, is used for land reclamation or compost production or it is landfilled. However, the incineration of sludge is a way that is able to significantly eliminate the risks associated with levels of undesirable minor components contained in sludge. Incineration of sludge is a modern technology which is considered as a modern basis in dealing with sludge issues.

The calorific value of the raw sludge or product of anaerobic fermentation is significantly reduced to values from 1 to 3 GJ/t due to water content of about 65 to 70 % after mechanical dewatering (Elsäßer, 2009) and late (Elsäßer, 2012) and problematic of mechanical dewatering is summarised by Ning (2013). The aim of this paper is to determine under which conditions the sludge incineration process is energy self-sufficient. The paper presents results of a series of balance calculations to determine the optimum rate of drying of raw or anaerobically pre-treated sludge so that the caloric content of the combusted material is sufficient to meet the energy needs of its own technology for energy production intended for export. It is shown that energy production can be significantly affected if the partial drying of the material after mechanical dewatering by waste heat from other operations becomes available. This article builds on the contribution of Fryba (2013) and discusses the conditions of sewage sludge incineration in detail.

1. Possible options for treatment of sewage sludge

There are many options for sewage sludge treatment which include distinct combinations of processing steps. Figure 1 shows the options most commonly used worldwide. Because the focus of this article is thermal treatment of sludge, the alternative processing methods are only briefly described below.

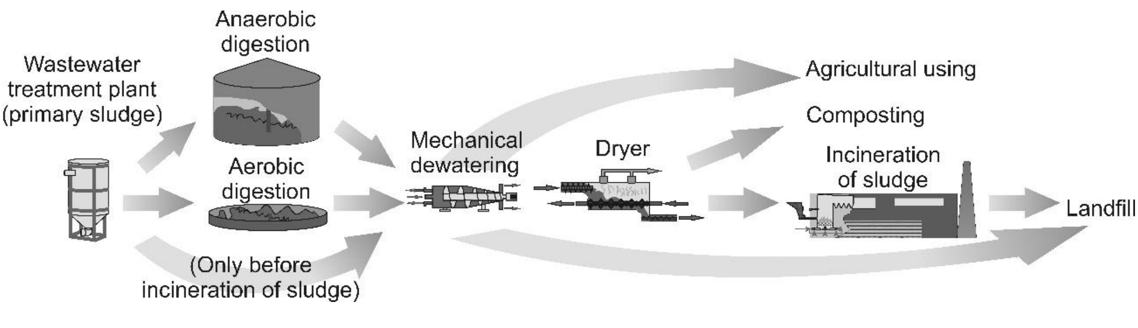

Figure 1: Possible options for treatment of sewage sludge

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1.1 Incorporation of sewage sludge application on agricultural land

Incorporation of sludge to land is generally on the decline. The reason is the need to comply with the limits specified in the relevant legislative standards for disposition on agricultural land in all seasons, and the public unwillingness to accept this kind of risk to health and the environment (Šťasta, 2006).

The use of sewage sludge as compost additives is how to use sludge on agricultural land as fertilizer and also faces a relatively high standard of quality of the product. Obviously, any changes in this field will probably lead to even stricter regulation which will disqualify this method, although it is established as one of the preferred methods in the hierarchy of sludge management in European laws. It is due to variable composition of the sludge and the economy of the entire compost production. Even though many companies dealing with industrial sewage sludge composting have emerged recently, their limited capacity cannot cover the total sewage sludge production of larger urban areas. The economic feasibility of such operations is nowadays still problematic.

The use of sludge in agriculture (directly applied or composted) will be possible for only a very limited amount of sludge, as stricter and stricter demands on sludge quality have to be met. Before the introduction of new legislation in various European countries (Switzerland, Germany, Finland, etc.) around 40 % sludge had been used in agriculture (Eurostat, 2014).

1.2 Incineration of sewage sludge

Incineration of sewage sludge with energy recovery is a useful method for minimization of risks associated with hazardous components of sludge. It is therefore considered as an important option in addressing sewage issues, especially in developed European countries. It is allowed to using mixed raw sludge (MRS) without sludge digestion only at sludge incineration (Figure 1). Next condition for using without digestion is thermal processing of sludge immediately after their production at wastewater treatment area.

2. Technology model for computation

Flow sheet of sewage sludge incineration plant is shown in Figure 2. The main technology units are sludge dryer, boiler and equipment for energy recovery of produced flue gas.

The technology includes a sludge dryer, which uses part of the steam after expansion in the turbine. The dryer utilizes thermal energy to evaporate water content down to the required percentage and for preheating of the remaining sludge.

Pre-heated air with temperature of 100 °C is considered for sludge incineration process. This temperature is achieved by heating the ambient air by waste heat in hot water at the outlet from the dryer and possibly by steam at the outlet of the turbine. The flow rate of air is calculated to achieve the flue gas temperature of 870 °C at the outlet from the boiler. The resulting excess air is based on the energy balance of the incineration process.

The flue gas heat capacity is utilized for hot steam production with parameters 4 MPa and 400 °C. The flue gas after heat recovery continues to flue gas treatment system. Energy consumption of flue gas treatment system is out of the scope of this paper, although it is expected that its performance will affect energy consumption technology. The flue gas cleaning system requirements are analysed by Kropač (2013).

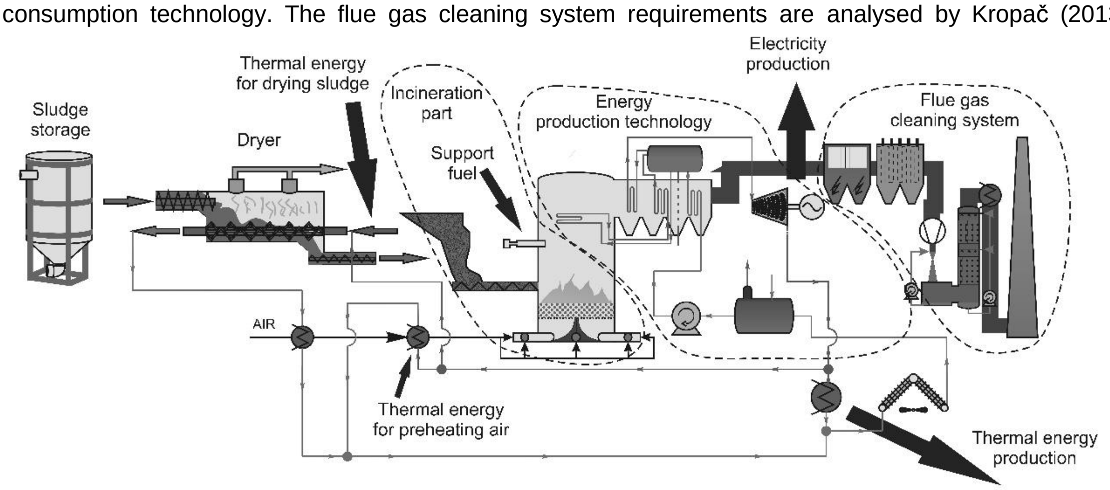

Figure 2: Technology for incineration of sewage sludge with main energy flows

Steam from energy recovery system is utilized at back-pressure turbine with output pressure of 0.6 MPa and thermodynamic efficiency of 80 %. Corresponding temperature of steam at the output from turbine is 200 °C. Steam is used in the dryer, and possibly for preheating the combustion air. As mentioned earlier in this section. The remaining heat in the steam at 200 °C is considered as the energy produced for heating purposes together with produced electricity.

3. Input parameters for calculations

As mentioned in the chapter 1, two options for thermal treatment of sludge are considered. Mixed raw sludge mechanically dewatered to 33 % wt. of solids content is a fuel assumed in the first option. In the other case, digested sludge (DS) after anaerobic stabilization or mixed raw sludge (MRS) are considered as a fuel. The chemical composition of the dry solid in mixed raw sludge and digested sludge is specified in Table 1 (Houdková, 2008).

Anaerobic stabilization makes mixed raw sludge hygienizated and biogas is produced at the same time. Biogas production results in a significant reduction in caloric content of residual sludge. Simplified balance of anaerobic stabilization is presented in Chapter 4. Biogas is usually used in combined heat and power production units.

Equations compare lower heating values (LHV) of DS - Eq(2) and MRS - Eq(1) as a function of dry solid content (x_{dry}) clearly. These equations were computed from considered composition at Table 1 by Waste to Energy (W2E) Software (Pavlas, 2010). It is necessary to note, that dry MRS has calorific value similar to brown coal solids and DS similar to municipal solid waste.

$$LHV_{MRS}\,[kJ/kg] = -2453.8 + 180.646 \cdot x_{dry}\,[\%\,wt.] \tag{1}$$

$$LHV_{DS}\,[kJ/kg] = -2453.8 + 131.636 \cdot x_{dry}\,[\%\,wt.] \tag{2}$$

4. Energy production from thermal processing of sludge

Main energy flow rates are summarized in Table 2 and Table 3, for incineration of MRS and DS, respectively. This energy flow rates are calculated for 1 t of solid dry content of sludge. Thermal energy is calculated from steam flow rate and enthalpy change of steam (temperature change is from 200 °C gas phase to 150 °C liquid phase) at pressure 0.6 MPa.

Table 1: Considered composition of dry solid in sludge (Houdková, 2008)

Composition		DS	MRS
C	[% wt.]	27.59	40.72
H	[% wt.]	3.64	4.40
N	[% wt.]	3.25	5.64
O	[% wt.]	9.50	16.75
S	[% wt.]	0.02	0.03
Cl	[% wt.]	0.00	0.01
F	[% wt.]	0.00	0.01
P	[% wt.]	0.00	0.00
Ash	[% wt.]	56.00	32.43

DS calculation at Table 3 did not consider energy production from utilization of biogas at cogeneration unit. Processes of anaerobic stabilization are described for example by Beno (2009). Energy from anaerobic digestion is usually used at wastewater treatment area for production of electricity and thermal energy. Produced energy from biogas is not usually sufficient for requirement of wastewater treatment technology. Example of energy production using cogeneration unit Motorgas MGW 700 shows Table 4.

Main energy flow rates production are shown in Figure 3. As can be seen from these results, incineration of sludge obtained from dewatered DS (approximately 33 % wt. solids) is not possible without extra energy supply. It should be noted that these results include only main energy demanding processes (drying, combustion, air pre-heating) and do not include other processes requiring energy heat supply (e.g. flue gas pre-heating for flue gas treatment system) electricity supply (e.g. flue gas fan, manipulation unit for fuel and sorbent, electrostatic precipitator, traffic management and controls). Energy produced by thermal processing of MRS is expected to cover these energy demands (Figure 1). When incinerating DS, it is necessary to utilize external energy for sewage sludge drying (e.g. waste thermal energy from parallel unit). Thermal processing of DS could be considered in that case.

Table 2: Energy flow rate from incineration of primary sludge

Dry solid content of sludge	[% wt.]	40	50	60	70	80	90	95
Caloric value of sludge (after drying)	[GJ/t_{MRSdry}]	11.87	13.10	13.91	14.50	14.94	15.28	15.42
Energy input from support fuel combustion	[GJ/t_{MRSdry}]	6.30	2.16	0.04	0.04	0.04	0.04	0.04
Air excess at sludge incineration	[GJ/t_{MRSdry}]	2.40	2.40	2.47	2.69	2.86	3.00	3.05
Thermal energy for drying input sludge	[GJ/t_{MRSdry}]	-1.67	-2.55	-3.29	-3.89	-4.35	-4.67	-4.77
Thermal energy for primary air preheating	[GJ/t_{MRSdry}]	-0.98	-0.95	-0.92	-0.89	-0.86	-0.83	-0.82
Electric energy production	[MWh/t_{MRSdry}]	0.486	0.412	0.380	0.397	0.411	0.422	0.427
Thermal energy for export (without energy from support fuel)	[GJ/t_{MRSdry}]	2.00	3.59	4.34	4.13	4.00	3.96	3.96

Table 3: Energy flow rate from incineration of anaerobic stabilised sludge

Dry solid content of sludge	[% wt.]	40	50	60	70	80	90	95
Caloric value of sludge (after drying)	[GJ/t_{DSdry}]	7.03	8.26	9.07	9.66	10.10	10.44	10.58
Energy input from support fuel combustion	[GJ/t_{DSdry}]	10.08	6.21	3.24	1.18	0.04	0.04	0.04
Air excess at sludge incineration	[GJ/t_{DSdry}]	2.80	2.80	2.80	2.80	2.84	3.04	3.13
Thermal energy for drying input sludge	[GJ/t_{DSdry}]	-1.75	-2.68	-3.42	-4.00	-4.39	-4.62	-4.66
Thermal energy for primary air preheating	[GJ/t_{DSdry}]	-0.67	-0.53	-0.44	-0.41	-0.44	-0.52	-0.58
Electric energy production	[MWh/t_{DSdry}]	0.448	0.378	0.325	0.289	0.270	0.280	0.285
Thermal energy for export (without energy from support fuel)	[GJ/t_{DSdry}]	-2.42	-0.99	0.10	0.85	1.24	1.17	1.14

Table 4: Energy production at cogeneration unit from created biogas at process anaerobic digestion primary sludge

Biogas production	[m_N^3/t_{MRSdry}]	264
Electric energy production	[MWh/t_{MRSdry}]	0.562
Thermal energy production	[GJ/t_{MRSdry}]	0.904

Comparison of possible energy production from incineration of MRS and DS for export is shown in Figure 4. Input flow rate of solid dry content of DS with using biogas production (Table 4) is stated at 0.615 t_{DSdry}/t_{MRSdry}. This production is calculated from composition of MRS and biogas production by energetic and material balance. All simulations were performed using Waste to Energy (W2E) Software tool. Description of the W2E tool is introduced by Pavlas (2010) and later Kropáč et al. (2011).

5. Conclusions

After inclusion of all energy requirements for the thermal processing caloric content of dry matter of digested sludge is insufficient and needs an external energy. In this case, it cannot be stated that it is the energy utilisation of sludge, but it should be mentioned only as a thermal disposal of sludge.

Thermal processing of digested sludge for energy utilization is not possible. Another reasons are high investments and energy requirements for anaerobic sludge digestion. In terms of energy production and efficiency of the plant is the best to thermally processed raw primary sludge which is dry in the range from 65 to 70 % wt. dry solid content. This dry solid content of sludge provides electricity production from 0.39 to 0.4 MWh/t_{MRSdry} and export of heat from 4.13 to 4.25 GJ/t_{MRSdry}. It is necessary to note that the energy gains are only computed with thermal part of the technology without flue gas cleaning stage. The future work will be focused on extending the energy demands of flue gas treatment.

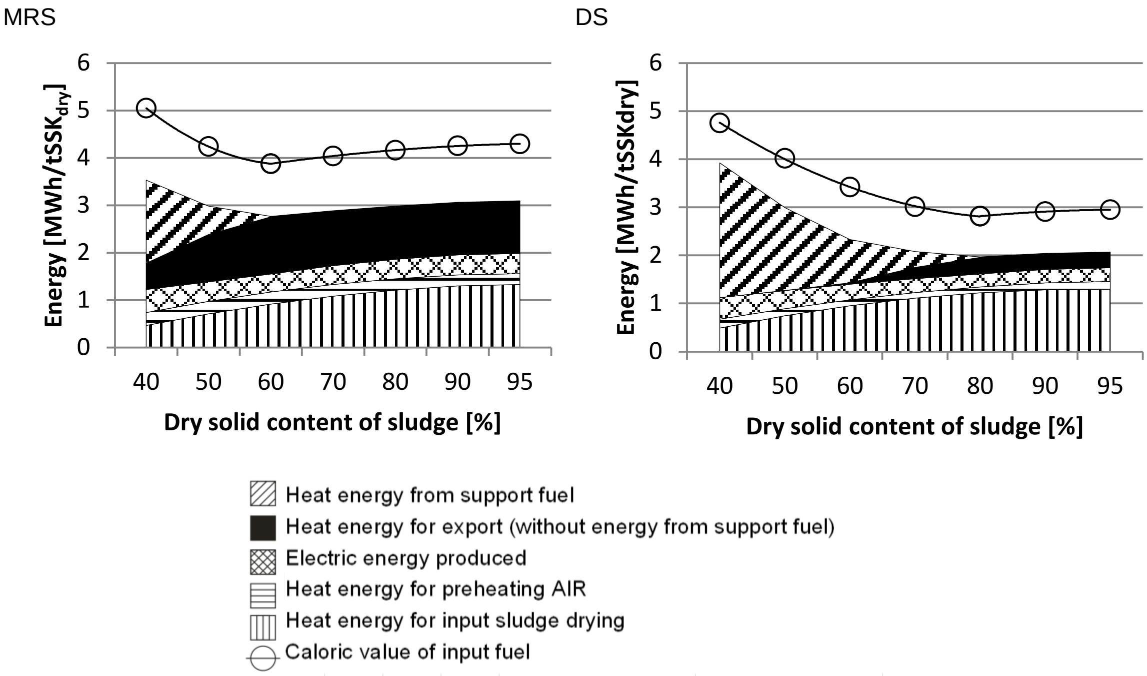

Figure 3: Possible energy production (MWh/tdry) from incineration of sewage sludge

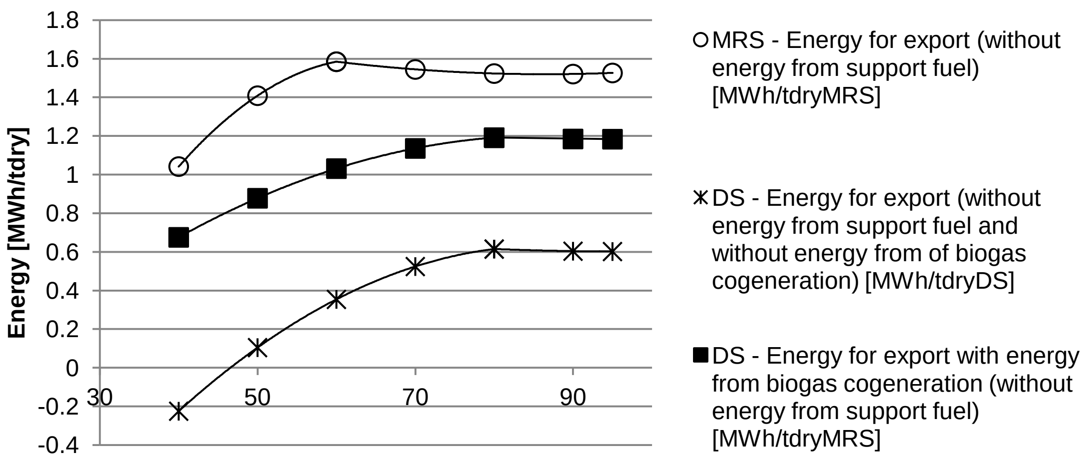

Figure 4: Possible energy production for export (district heating purposes) from incineration of sewage sludge

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