THERMAL UTILISATION OF BIOLOGICALLY STABILISED AND DRIED WASTE SLUDGE FROM WASTEWATER TREATMENT PLANTS

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SUMMARY: Results of a research project aiming at development of an efficient process for thermal utilization of the stabilized dehydrated sewage sludge is presented. The only remaining domestic option in new circumstances seems to be conversion of sludge to alternative solid fuel, which – when set of legal quality requirements is met – may be co-incinerated in industrial thermal processes. Newly issued regulation on conversion of nonhazardous wastes to alternative solid fuels sets relatively strict limits for calorific value, sulfur and chlorine content as well as mercury and cadmium content. This is the factor which can be improved and was the subject of this study. The project was aimed at revealing a set of practical means for matching exceeded limit values of certain parameters (sulfur and mercury content) by preventive and remedial approaches. Conformity of critical parameters to the limit values have been studied over two years period. Discrepancies are recorded statistically and preventive measured suggested for critical parameters to keep them in acceptable range.

1. INTRODUCTION

By the end of last century all Slovene towns above 10.000 inhabitants were equipped with sewer systems and wastewater treatment plants. Biologically supported degradation of impurities has resulted in production of sewage sludge in quantities about 20.000 tones of dry matter (about 100.000 tons of raw sludge containing 20-25 % of dry matter. The conventional methods of disposal were landfilling (70 %) and land use (30 %).

1.1 Changing legislation

In the year 2008 the Slovenian legislation of wastes management was almost completely renovated. Following the European waste management hierarchy (Directive, 2008) new regulations were issued, which banned disposal of biological waste, among them also sewage sludge. New, stricter quality criteria were also set for waste in agriculture (the second important option), that most sludges could not have met. Thermal treatment seemed to be the only solution; however there was no industrial scale incinerator in the country and public was strongly against

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installing a new one. In this situation the only remaining domestic option for organic wastes having certain calorific value was transformation to an alternative solid fuel (or solid recovered fuel, SRF). These may be used in coal-fired power plants or some industrial thermal processes, e.g. cement production. The related legislation demands are (Ordinance 2008):

- only non-hazardous waste may be processed to alternative fuel
- the fuel must conform to the prescribed quality parameters (Table 1)
- a control system must be set up in order to allow permanent insight to the fuel quality.

There has been no problem regarding the first criterion, since Slovene sewage sludges are non-hazardous. Most critical is the next one, since the alternative fuel must conform to a new set of quality standards, which are mainly dictated by strict environmental protection principles. The alternative solid fuels are classified into five quality classes, depending on the mean (or median) content of cadmium, mercury, chlorine, sulfur and the calorific value of waste. The set of limiting parameters is larger than in the related European technical specification TS CEN/TS 15359, which does not include cadmium and sulfur.

The size and type of the incineration plant are as well regulated, the smallest power plant applicable being 1 MW_{th}. The solid fuel can be made (among other types of waste) from processed sludge from municipal or industrial biological waste water treatment plants, as well as the sludge from an anaerobic digesting process. The fuel also has to be classified according to:

- net calorific value, into the 1st, 2nd or 3rd class from the classification list of SRF,
- content of chlorine, into the 1st or 2nd class,
- content of hazardous substances (mercury, cadmium and sulfur), into the 1st class from the classification list of solid recovered fuels.

For thermal units larger then 50 MW, minimal quality of SRF should be in the range of the defined five classes, however the plat must obtain an environmental permit for the processing of such a waste by the R1 procedure, that includes meeting air emission requirements concerning, set by the regulation on incineration and co-incineration of waste.

The operator of an alternative fuel production process must establish and maintain a quality control system which allows continual collection of relevant data about the produced fuel, stored and dispatched to the users. The regulated quality of processed sludge includes monitoring of fuel properties at least 10 times per year or every 2000 tons of produced fuel. Reporting to the legislator must be made once a year, containing statistical data of shorter list of parameters as well as analytical results on broader list of parameters in a composed sample, made from average monthly samples or of lots placed on the market during last year.

The aim of this contribution is to present some useful data, experience and main problems of operation and control of dry sewage sludge production process and utilization of the produced alternative fuel. Some ideas for future developments are also given regarding integration of other

Table 1 - Limit values of solid recovered fuel classes according to Slovene legislation.

Parameter	Given as	Unit	Class limit values				
			1st class	2nd class	3rs class	4th class	5th class
Net calorif. value	arith.mean	MJ/kg_{ar}	≥25	≥20	≥15	≥10	≥3
Chlorine	arith.mean	$\%_{d}$	≤0.2	≤0.6	≤1.0	≤1.5	≤3
Sulfur	arith.mean	$\%_{d}$	≤0.2	≤0.3	≤0.5	≤0.5	≤0.5
Mercury	median	mg/MJ_{ar}	≤0.02	≤0.03	≤0.08	≤0.15	≤0.5
Mercury	80 % perc.	mg/MJ_{ar}	<0.04	≤0.06	≤0.16	≤0.30	≤1.0
Cadmium	arith.mean	mg/kg_{ar}	≤1.0	≤4.0	≤5.0	≤5.0	≤5.0

plant wastes and minimization of the effect of toxic organic and inorganic components, present in the sludge.

1.2 The plant and the sludge considered

Excess sludge, generated during the biological treatment of waste waters represents the largest share of wastes in municipal waste water treatment plant of Ljubljana. Its size of near 400.000 PE makes it the largest waste water treatment plant in Slovenia. It is designed as a mechanical treatment plant in the first step for the removal of suspended particles, followed by a biological plant as a secondary step of cleaning which allows removal of carbon compounds and nitrification. Excess sludge, formed in the aerobic treatment process, containing 0.65 % to 1.2 % of dry matter, is simultaneously extracted from the system. After primary (gravitational) thickening in settling tanks the sludge undergoes mechanical thickening with an addition of polymer, so that the content of dry substance increases up to 6 %. Follows the anaerobic stabilization of sludge (together with sludges from some dislocated treatment plants, septic tanks contents and some other similar wastes from the region) in an anaerobic digester where the content of dry substance is reduced to around 4 % on behalf of biogas production. Anaerobically stabilized sludge is mechanically dehydrated by a vibrating gravity settler and a centrifuge to about 25-30 % dry matter an then dried in a rotating drum, heated by biogas from digesters and some natural gas to obtain 3-5 mm granules of 91 % dry matter, which are air-cooled and stored in a bunker before used as an alternative solid fuel (mostly in a cement kiln). Typical annual capacity of the sludge treatment plant is between 4500 - 5000 tons of stabilized dry sludge and is still increasing.

1.3 Potential options for sludge utilization

The wastewater treatment plant under consideration is not equipped with an incineration unit, since this option of treatment had not been foreseen at the time of design and construction. To avoid the high costs of incineration of sludge abroad, it was offered to the Slovene cement factories and to the coal-fired power plants as a supplement fuel. In that case, beneficial use of dry sludge heat content can be made on existing installations, equipped with an appropriate exhaust gas treatment system. The amount of co-fired sludge in such cases would be small compared to the amount of primary fuel (coal or coke), so that the effect of sludge on the air quality may be neglected. Furthermore, sludge mineral composition (the remaining ash) consists of Mg, Ca, Al, Fe and Si oxides, thus being fully compatible with klinker minerals or coal ash.(Scheuer 2002)

2. FUNDAMENTALS OF SLUDGE UTILISATION

Sustainable wastewater management means reduction of pollutants (primarily by avoiding the use of most harmful substances at source) and recycling of the sewage sludge, once being produced in the wastewater treatment process. This approach somehow matches the continuous increase in sludge production, high costs of sludge treatment, and risks that sewage sludge may have on the environment and human health. The increasing awareness regarding risks for the environment, the use of sludge as a fertilizer in agricultural sector has become very limited. Policy and legislation regarding sludge management (preferentially some sort of recycling) in general are strongly dependent upon local and regional conditions. The costs of sewage sludge treatment represent about 50 % of the total wastewater treatment costs. Municipal wastewater treatment can be considered as a continuous activity, since fresh water supply is a basic commodity of civilized world. This means that the quantity of the sewage sludge will not change significantly in the future, may be of improved quality (less polluted). Sewage sludge remains a problem to every municipality that requires an appropriate rational solution. Progress in development of sludge management offers innovative treatment methods like recovery and reuse of valuable products from sludge or a complete utilization of the sludge, with acceptable costs. In this respect, the recovery of sustainable energy from sewage sludge is becoming more and more of interesting and economically acceptable.(Rulkens 2008)

To prove the applicability of a chosen option of sludge management, it is necessary to look at the composition of the sludge, especially regarding content of: i) organic carbon compounds, ii) inorganic compounds (mainly earth minerals), iii) nitrogen and phosphorous-containing components, iv) inorganic micro pollutants (heavy metals), v) persistent organic pollutants (PAH, PCB etc.), vi) pathogens and other microbiological pollutants, vii) water and viii) heat content (calorific value). Sustainable treatment involves the recovery and useful reuse of the valuable components or at least its heat content and the minimization of the possible adverse impact of sewage sludge or residues on the environment and humans. For efficient thermal utilization most important property is the calorific value, which is determined by organic fraction and sludge moisture. Hindering factors are the content of toxic pollutants and of pathogen microorganisms. (Scheule 2002, Takx 2002)

3. EXPERIMENTAL STUDY

3.1 Materials and methods

A system for quality control of the solid recovered fuel, made from sewage sludge, was set-up according to the technical specification TS CEN/TS 15358 (TS 2007).

A sampling plan was prepared according to the standard EN 14899 for provision of needed statistical data on annual variation of prescribed dry sludge/SRF properties (EN 2006). According to the plan two types of samples were collected by means of probabilistic sampling:

- freshly dried sludge from the conveyor belt, leading from drier to the storage bunker; one increment sample of 0.5 kg every three hours, every operating day (five days a week);
- solid recovered fuel, one sample of 2 kg of every lot, fed into a transport tankard; usually one lot per working day.

The increment samples were mixed together into daily samples and stored in a fridge; consecutively daily, weekly, monthly and yearly composite samples were prepared and analyzed to obtain average values and time fluctuations of the product.

In order to provide information on time fluctuations of sludge composition analyses were made of:

- one random set of increments, taken during one day (8 increment samples),
- one random set of composed daily samples of 5 consecutive days,
- one random set of composed weekly samples of 4 consecutive weeks and
- One random set of composed samples of 11 consecutive months.

Samples of the dispatched lots of SRF were analyzed on three basic parameters (moisture, ash and calorific value). One set of samples from one month was mixed and analyzed for comparison with corresponding monthly sample of dry sludge from the belt.

Standard analytical methods for characterization of wastes or solid recovered fuels were applied, as prepared by Technical Committees CEN/TC 292 “Characterization of waste” and CEN/TS 343 “Solid recovered fuels”, shown in Table 2.

Table 2 - Standard methods for characterization of wastes, used in this study.

Parameter	Method
Sampling	SIST* EN 14899
Homogenization	SIST EN 15002
Leaching test	SIST EN 12457-4
Dry residue	SIST EN 14346
Volatile matter	SIST EN 15169
Calorific value	SIST EN 15400
pH	SIST EN 12506, ISO 10523
Heavy metals	SIST EN ISO 17294-2, ISO 5666
Chlorine	DIN 51577, SIST ISO 9297
Total organic carbon -TOC	SIST ISO 609 and 10693

* Slovene standards, identical with the corresponding European standards

4. RESULTS AND DISCUSSION

4.1 Quality of the SRF, made from the sewage sludge

Most important statistical values of the prime regulated parameters of SRF, prepared from three-hour increments over different time periods within 12-months period in which quality management system is applied are given in Table 3. It can be seen that variations of the classification properties, measured by standard deviation or coefficient of variation, increase with the time period, for which the composite samples were prepared. The largest oscillation show analytical data of sulphur and the smallest of mercury. The range of oscillations confirms the need to use statistical values like median and percentiles, rather than arithmetic mean in presentations of average quality of the alternative fuel on the basis of time series of data.

Table 4 shows classification of the solid recovered fuel from the sewage sludge using limit values from Table 1. The quality parameters differ very much, chlorine and cadmium being in the first class, mercury and calorific value in the last (fifth) class, whereas sulphur is out of limit values. Quality of the SRF from dry sewage sludge is thus controlled with the content of sulphur, mercury and organic matter (responsible for calorific value). This quality of SRF does not satisfy the legislative criteria for its application in normal coal fired power plants. It can be co-incinerated in large industrial thermal processes, equipped with gas emission treatment systems, like cement kilns. According to technical specification CEN/TS 15359, which specifies smaller number of classification parameters the fuel would be assigned with the code NCV 4; Cl 1; Hg 5. Two of three attributes fall in two lowest quality classes.

Beside to the classification, the SRF producer must provide also its specification. Table 5 shows data on broader list of y parameters, which are obligatory to be specified for a particular SRF, in our case made from sewage sludge.

Table 3 - Dependence of statistical values of dry sludge samples with time scale of composite samples.

Parameter	Statistical variable	Variation between composite samples				
		Hourly	Daily	Weekly	Monthly	**Ratio monthly/daily**
		(8 increments)	(5 comp.samples)	(4 comp. samples)	(11 comp. samples)	
Moisture	Average (%)	92.76	93.48	93.43	92.450	
	Stand. deviation (%)	0.0744	0.117	0.299	0.945	
	Coeff. of variation (-)	0.0008	0.0013	0.0032	0.0102	12.8
Volatiles	Average (%)	50.69	51.75	51.30	62.71	
	Stand. deviation (%)	0.405	0.551	1.673	4.20	
	Coeff. of variation (-)	0.0079	0.0106	0.0326	0.0670	8.5
Net calorific value	Average (MJ/kg)	10.560	10.956	10.837	10.250	
	Stand. deviation (MJ/kg)	0.0880	0.1476	0.3390	0.8353	
	Coeff. of variation (-)	0.0083	0.0135	0.0313	0.0815	10.6
Chlorine	Average (%)	-	0.0494	0.0490	0.0577	
	Stand. deviation (%)	-	0.0024	0.00274	0.0146	
	Coeff. of variation (-)	-	0.0486	0.0559	0.253	5.2
Sulfur	Average (%)	-	0.592	0.586	0.637	
	Stand. deviation (%)	-	0.0084	0.0249	0.150	
	Coeff. of variation (-)	-	0.0142	0.0425	0.2355	16.6
Mercury	Average (mg/kg)	-	1.48	1.75	1.65	
	Stand. deviation (mg/kg)	-	0.110	0.370	0.7769	
	Coeff. of variation (-)	-	0.0743	0.2114	0.4708	6.3
Cadmium	Average (mg/kg)	-	-	-	0.96	
	Stand. deviation (mg/kg)	-	-	-	0.081	
	Coeff. of variation (-)	-	-	-	0.0844	-

Table 4 - Average properties of SRF, obtained from sewage sludge (I-XI.2009).

Parameter	Unit	Values	
		Typical	Limit values and the class
Calorific value	MJ/kg_{ar}	10.3	10 (class 4)
Chlorine	$\%_{d}$	0.06	0.2 (class 1)
Sulfur	$\%_{d}$	0.6	0.5 (out of range)
Mercury, $_{med.}$	mg/MJ_{ar}	0.16	0.5 (class 5)
Mercury, 80%	mg/MJ_{ar}	0.17	0.3 (class 4)
Cadmium	mg/kg_{d}	<1	1 (class 1)

Table 5 - Specification of the SRF, made from sewage sludge, according to CEN/TS 15359.

SRF Class and origin				
Class code: NCV 5; Cl 1; Hg 5				
Origin: Sewage sludge from central wastewater treatment plant				
Physical and chemical parameters				
Particle form: round granules				Test method
Particle size: d_{10}=2.1mm, d_{50}=2.6 mm, d_{90}=3.1mm				CEN/TS 15415
Bulk density: 676 kg/m^3				CEN/TS 15401
Attrition strength: 95.6 %				CEN/TS 15639
Ignition temperature: 570°C				Internal
		Value		
Parameter	Unit	Typical	Limit	
Ash content	$\%_{d}$	36.8	-	CEN/TS 15403
Moisture cont.	$\%_{ar}$	7.64	-	CEN/TS 15414
Net calorif. value	MJ/kg_{ar}	10.39	3-25	EN 15400
Net calorif. value	MJ/kg_{d}	11.10	-	EN 15400
Chlorine	$\%_{d}$	0.076	0.2-3	DIN 51577, SIST ISO 9297
Antimony	mg/kg_{d}	<20	-	EN ISO 17294-2
Arsenic	mg/kg_{d}	<20	-	EN ISO 17294
Cadmium	mg/kg_{d}	1	-	EN ISO 17294
Chromium	mg/kg_{d}	89	-	EN ISO 17294
Cobalt	mg/kg_{d}	<20	-	EN ISO 17294
Copper	mg/kg_{d}	235	-	EN ISO 17294
Lead	mg/kg_{d}	74	-	EN ISO 17294
Manganese	mg/kg_{d}	275	-	EN ISO 17294
Mercury	mg/kg_{d}	1.96	-	ISO 5666
Nickel	mg/kg_{d}	49	-	EN ISO 17294
Thallium	mg/kg_{d}	<10	-	EN ISO 17294
Vanadium	mg/kg_{d}	<20	-	EN ISO 17294
Sum heavy metals	mg/kg_{d}	<815	-	-

4.2 Some actions towards increasing the fuel quality

Sulfur content: There are several reasons for high sulfur content in the SRF from sewage sludge. The first are sulfate minerals in incoming water and particulates. The main process reason is probably the use of mineral flocculants (e.g. aluminum sulfate). Sulfates are reduced and may form H_2S, which is precipitated from biogas with ferric chloride solution. Sulfate additives should therefore be avoided and H_2S treated in such a way that sulfur is eliminated from the system.

Mercury: Mercury enters the in wastewater system mainly in a form of suspended particles, waste sludges from small treatment plants and septic tanks. Its presence is stable in small amounts, but on the very limit of tolerance for SRF. Only upstream prevention measures are possible to reduce the sludge contamination with mercury.

Calorific value: Can be increased by decreasing content of mineral (inorganic) fraction, i.e. by improved primary settling. Biological stabilization of sludge by digestion also decreases carbon content, however on behalf of the biogas production that is beneficial for consecutive sludge drying process. Carbon content can be increased by addition of other types of biodegradable wastes to the digestor (Mislej 2010, Šalej and Grilc 2009):

- from wastewater sector: non-stabilized sludges from small WWTP, septic tank contents and other types of wastes from WWTP e.g. screenings;
- from waste sector: biodegradable fraction of municipal solid waste (from MBT process), bio-wastes from industry and agriculture etc..

5. CONCLUSIONS

Options for surplus sewage sludge disposal are getting very scarce. This makes the cost of disposal high. Anaerobic stabilization of raw sludge from wastewater treatment process hardly provides enough biogas to make the sludge dry, as required for an alternative solid fuel. Calorific value of the solid recovered fuel made from sewage sludge is about 10 MJ/kg (like lignite); however there are various pollutants present. Quality control system must be established for permanent monitoring of the fuel compliance to the legal requirements. Analytical values of limiting parameters show much variation with time so statistical values should be used.

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