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ENVIRONMENTAL MANAGEMENT OF THE SEWAGE SLUDGE: CASE STUDY – THE WASTEWATER TREATMENT PLANT OF TIMISOARA

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Original scientific paper

When we talk about the sewage sludge, we refer to the excess of the sludge resulting from the wastewater treatment plants. The EEC Directive 91/271, referring to the Urban Waste Water Treatment, modified by the EEC Directive 98/15 is implemented in Romania also. This requires that until 31 December 2018, all localities with more than 2000 population equivalent (p.e.) must be served by sewerage networks and wastewater treatment plants where the resulting sludge should be managed ecologically. Therefore it is necessary to implement urgently an environmental management strategy of the sludge. The ecological studies on the sewage sludge management in short (2013), medium (2020) and long (2040) term were made in the EU in 2008 and in Romania in 2012. Both in the EU and in Romania the main option is to use the sludge on agricultural land as organic fertilizer but also to use the sludge as an energy source recovered by combustion. For an efficient management, in both cases there is a need for the sludge dewatering and drying. Thus the sludge volume will decrease, the transport and storage costs will be significantly reduced, and the lower heat value (u_l) will increase. As a main conclusion one will support the idea that it is necessary to make a preliminary assessment of the thermodynamic energy content of the sewage sludge in order to depict and select the global vision of the process, assuring both the optimal energy development and environmental friendly treatment processes.

Keywords: *combustion, energy recovery, environmental management, sewage sludge, thermodynamic cycles, wastewater*

Ekološko gospodarenje otpadom iz kanalizacije: analiza slučaja – postrojenje za preradu otpadnih voda u Temišvaru

Izvorni znanstveni članak

Kad govorimo o otpadu iz kanalizacije mislimo na suvišni otpad iz postrojenja za preradu otpadnih voda. EEC Uputstvo 91/271, koje se odnosi na preradu otpadnih voda u gradovima, modificirano EEC Uputstvom 98/15 primjenjuje se i u Rumunjskoj. Prema njemu do 31. prosinca 2018. sva mjesta s populacijskim ekvivalentom (p.e.) većim od 2000 moraju imati mreže kanalizacije i postrojenja za preradu otpadnih voda u kojima će se nastale otpadne tvari ekološki tretirati. Potrebno je stoga hitno primijeniti strategiju ekološkog gospodarenja otpadnim vodama. Ekološke studije o upravljanju kanalizacijskim otpadom u kratkom (2013), srednjem (2020) i dugom (2040) vremenskom periodu su u EU provedene 2008. godine, a u Rumunjskoj 2012. I u EU i u Rumunjskoj osnovna opcija je korištenje otpadnih tvari kao organskih gnojiva na poljoprivrednim površinama, ali i njihovo korištenje kao izvora energije dobivene izgaranjem. Za učinkovito upravljanje, i u jednom i u drugom slučaju potrebno je odstranjivanje vode i sušenje. Tako će se količina taloga smanjiti, troškovi prijevoza i skladištenja znatno reducirati, a niža vrijednost topline (u_l) će porasti. Glavni je zaključak da treba podržati ideju o potrebi prethodne provjere iznosa udjela termodinamičke energije u kanalizacijskom otpadu kako bi se prikazala i odabrala globalna vizija postupka te osigurao razvoj optimalnog iznosa energije i postupci obrade ekološki prihvatljivi.

Ključne riječi: *ekološko gospodarenje, izgaranje, obnavljanje energije, otpad iz kanalizacije, otpadne vode, termodinamički ciklusi*

1 Introduction

Sewage sludge resulting from municipal wastewater treatment, industrial or domestic is officially classified as waste, but the accepted policy is to use the sludge beneficially whenever it is feasible, either as organic fertilizer on land or as an energy source recovered by combustion. We must be aware that scattering sewage sludge on agricultural land can cause health risks by the infestation of soil and groundwater with heavy metals, pathogenic agents and viruses.

These issues have generated particular interest in other disposal alternatives, one of which is the burning of sludge, thus removing potential pollutants from the food processing chain. The result of incineration is a small amount of suspended solids that can be removed easily. In addition, it is possible that the phosphorus within the ash be used as fertilizer in agriculture. Heavy metals can also be recovered and recycled. In case of energy recovery by burning sludge an optimized technological version should be chosen, which should be able to provide maximum energy efficiency, emissions and waste materials in small amounts and which are within the limits imposed for pollution.

2 Theory

Wastewater treatment plant operators must identify the best environmental solutions and practices for the treatment, recovery / disposal of sludge, both sustainable and efficient in terms of costs. When choosing the sludge treatment process we must take into account the sludge management strategy (removal/recovery), the wastewater treatment plants (WWTP). We have the following options:

1. Using the waste in agriculture by spreading it over the agricultural terrain, followed by its immediate incorporation or by creating a bed compost together with other materials and use it as subsequent fertilization of agricultural land;
2. Energy recovery of sludge by co-fermentation or anaerobic digestion with biogas production and eventually fermented sludge incineration technologies, or incineration without fermentation, the facilities being functional in co-generation system, transforming the energy content of the sludge into usable heat and electric power, finally used for own purposes by the producer, in order to reduce its energy costs for the treatment processes of wastewater and sludge;
3. Co-combustion of sludge in solid waste incinerators under clean technologies and within high efficiency thermodynamic cycles;

4. Co-processing of sludge in the cement industry, if the humidity and calorific value of sludge meet the requirements of the production process.

3 Environmental management of the sewage sludge resulting from wastewater treatment plants in Romania and the EU

Using sludge in agriculture involves treating it, and the preferred method is anaerobic digestion. The result of this process is not only sludge stabilization and odour and pathogenic elements reduction, but also biogas production, which can be used as a source of heat and energy in wastewater treatment processes. Electricity from sewage sludge saves fossil fuels and reduces fossil originated CO_2 emissions.

Energy recovery from sludge for cogeneration of heat and power is achieved by using technologically advanced industrial and economically efficient plants, within advanced thermodynamic cycles.

In addition to achieving maximum energy efficiency it is very important to analyze and treat emissions and waste materials resulting from thermal treatment processes to minimize any possible environmental impact.

The energy produced will be used in wastewater and sludge treatment and it will help reduce the specific consumption of materials and energy.

3.1 Status in Romania

The developing of the infrastructure for wastewater collection and treatment in Romania, with respect to the Accession Treaty, lead to an increasing need for a national short, medium and long term sludge management strategy, the last variant being elaborated in February 2012 [3].

As it is the most complex option, sludge agricultural use is regulated by Order. 344 of August 16th, 2004 for approving the Technical Norms regarding environmental protection, especially soil protection, and when to use sludge in agriculture [4].

If we choose energy recovery from waste sludge by incineration, we should keep in mind the following national regulations (The SOP Environment Management Authority, 2012):

- Government Decision 128/2002 regarding waste incineration (Official Gazette, Part I, no. 160, of 06.03.2002);
- Government Decision 268/2005 (Official Gazette 332 of 20.04.2005) which modifies and completes GD 128/2002 regarding waste incineration;
- Order of the Ministry of the Environment and Sustainable Development 756/2004 for the approval of the Technical Norm for waste incineration (Official Gazette 86 of 26.01.2005).

The current research on ecological recovery of sludge from municipal wastewater treatment plants in Romania is at an early stage because starting only with 2010 have there been put into operation high-performance wastewater treatment plants, and only in big cities, usually in county capitals.

Several studies have been made to evaluate energy content of excess biological sludge derived from aerobic biological treatment of municipal wastewater in Timisoara. The study refers to the two different ways of exploiting the energy contained in sludge: the combustion of biogas resulting from anaerobic fermentation or the direct combustion of the sludge [1].

Studies for recovering energy from waste through co-combustion in solid waste incinerators were also made in other major cities in non-EU countries [2].

If we choose energy recovery from the sewage sludge, we should take into account that more energy will be obtained from raw sludge (unfermented). In this case fermentation is no longer necessary. Combustion of the sludge to reduce its mass and to recover energy is an important alternative to using sludge on land.

Sludge treatment stops for now at the preliminary treatment phases namely conditioning, thickening and dewatering to a dry solids (D.S.) content of min. 20 %.

From the 114 wastewater treatment plants which process sludge, functional at the end of 2011, only 2 (1,75 %) recover sludge by using it in agriculture, the others removing or storing it in various forms [3].

With increasing quantities of sludge resulting from putting new wastewater treatment plants into operation, from the total sludge production estimated for the end 2020, an amount of 415 600 t D.S./year, 50 % will be used in agriculture, 20 % will be incinerated and the remaining 30 % will be co-processed in cement plants. These figures are expected as a basic scenario, the use of sludge in agriculture being a priority [3].

Based on the evolution of energy consumption and reserves of conventional fuels an extreme scenario, "maximum EdD", was elaborated, which states that the total quantity of sludge produced in the year 2020, estimated at an amount of 415 600 t D.S./year, will be used for energy recovery by treating it in major regional treatment centres [3]. The main operations are:

- partial stabilization by anaerobic digestion with biogas production;
- dewatering;
- composting;
- drying;
- incineration and co-incineration;
- co-processing in cement plants.

Using the total sludge quantity of 415 600 t D.S./year, estimated for the end of 2020, one considers that energy will be recovered, in various ways, from the following quantities of sludge [3].

- 267 000 t (64,25 %) - by mono-incineration or co-incineration of sludge, with other conventional fuels or biomass;
- 147 400 t (35,45 %) - by co-processing in cement plants;
- 1200 t (0,3 %) - by composting.

3.2 Status in the EU

In the EU 15 environmental management of sewage sludge has become a priority for wastewater treatment plants operators with the implementation of Directives

86/278/EEC on using sludge in agriculture and 91/271/EEC concerning urban wastewater treatment.

Thus in the 15 European countries (EU 15) the amount of sludge used in agriculture increased from 3 Mt D.S./year in 1995 to 5,4 Mt in 2010 (an increase of 80 %) with an estimated increase in 2020, to 6,1 Mt D.S./year [5].

A greater emphasis was put on energy recovery from sludge incineration, so at the EU 15 level, the amount of sludge incinerated increased from 1,5 Mt D.S./year in 1995 to 3,1 Mt in 2010 (an increase of 106,7 %) with an estimated increase in 2020, to 3,6 Mt D.S./year [5].

Through the research-development activity and implementation of high technology in recovery renewable energy resources in Germany, energy recovery through incineration of sewage sludge increased significantly, from 9 % in 1991 to 53,2 % in 2010 (an increase of 491 %) of the total sludge produced, with a humidity of 60 % D.S. (Federal Institute of Ecology UBA 2011).

Sludge mono-incineration plants, in combined cycles, have been tested and developed in Germany beginning with 2005 at the Technical University of Braunschweig [6], as well as in the "HUBER - sludge2energy" technology [7, 8].

4 Case study – the wastewater treatment plant of Timisoara

The present case study refers to a possible solution for energy recovery by direct combustion of the sludge resulting from the municipal wastewater treatment plant in Timisoara. Because the WWTP Timisoara does not have sludge fermentation tanks for sludge stabilisation and biogas production, the excess sludge from the settlement tanks can be put into value from an energetic point of view by incineration in a thermodynamic cycle based on a thermodynamic cycle with a high efficiency.

The thermal treatment process of the sludge is a combination of dry sludge followed by a mono-combustion and power generation. The sludge drying is a special technology – known in literature as the drying technology "HUBER BT^{plus} Dryer Belt" The increase of the cycle's energetic efficiency is based on efficient recovery of the heat resulting from the burning of the sludge with the help of the regenerative heat exchanger conceived within the new Pebble-Heater technology and of the hot air turbines in the concept of SIEMENS AG [7, 8, 9, 10].

4.1 Methods

For estimating the thermal energy available by the incineration of sludge it is necessary to know two very important elements:

1. The lower heat value can be determined with an approximation equation, based on the chemical elementary analysis of the fuel;
2. The sludge mass flow input of the biomass combustor.

4.1.1 The lower heat value estimating

The lower heat value can be determined with an approximation equation, based on the chemical elementary analysis of the fuel as follow:

$$u_l = 33{,}9\cdot C + 120{,}12\cdot(H - O/8) + 9{,}25\cdot S - 2{,}51\cdot H_2O, \text{ MJ/kg, [11]} \quad (1)$$

$$u_l = 33{,}9\cdot C + 121{,}4\cdot(H - O/8) + 10{,}5\cdot S - 2{,}24\cdot H_2O, \text{ MJ/kg, [12]} \quad (2)$$

$$u_l = 35\cdot C + 94{,}3\cdot H + 10{,}4\cdot S + 6{,}3\cdot N - 10{,}8\cdot O - 2{,}44\cdot H_2O, \text{ MJ/kg, [12].} \quad (3)$$

For the Timisoara case study the basic start was accomplished in a composition analysis. The elementary analysis of the sludge resulted in the following chemical composition (in percentage by mass of dry substance) for components: carbon C – 30,35 %, oxygen O – 27,85 %, nitrogen N – 3,05 %, hydrogen H – 4,73 %, phosphorus P – 1,48 %, sulphur – 0,74 % and 31,8 % inorganic residue.

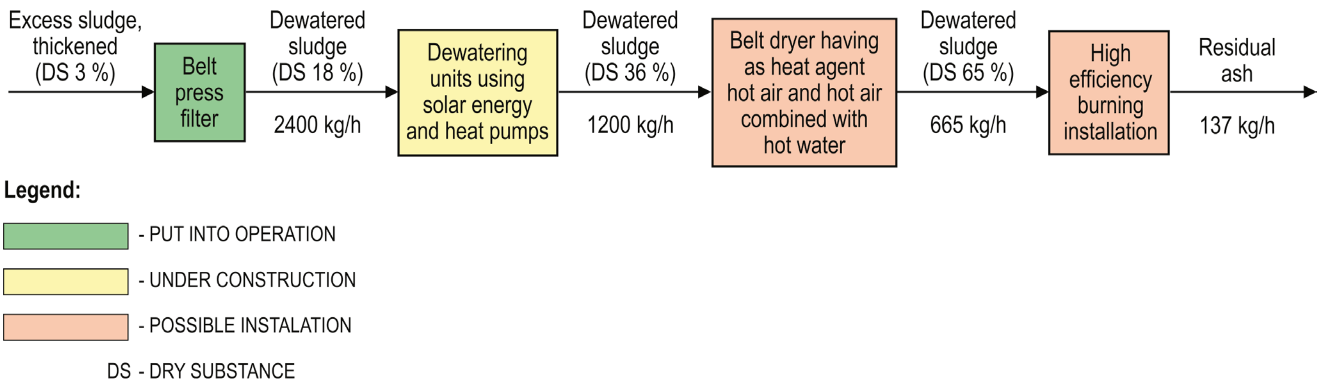

Figure 1 The possible technological flux for sludge dewatering at the Wastewater Treatment Plant Timisoara

After dewatering and drying, in view of incineration by mono-combustion, the sludge will reach a humidity of 35 %. In this case, the chemical composition is: carbon C – 19,74 %, oxygen O – 18,10 %, nitrogen N – 1,98 %, hydrogen H – 3,07 %, sulphur – 0,48 %, and 21,63 % phosphorous and the inorganic residue which are considered as constitutes of the mineral substances.

After calculations, the following values result for lower heat value:

$u_l\,(1) = 6{,}82773$ MJ/kg,

u_l (2) = 6,938565 MJ/kg,
u_l (3) = 7,16987 MJ/kg.

In order to estimate the energetic balance of the burning installation, an average value u_l =7,00 MJ/kg can be taken into consideration.

4.1.2 Estimating the sludge mass flow input of the biomass combustor

The mechanical and thermal processes for the reduction of the humidity of thickened excess sludge for the WWTP Timisoara take place according to the technological flux presented in Fig. 1. The sludge mass flow per thermal treatment flux is presented in Tab. 1.

Table 1 Mass flow per flux of thermal treated sludge, possible to be executed at the Wastewater Treatment Plant Timisoara

Treatment installation	Average the sludge mass flow input, kg/h	The sludge mass flow output, kg/h	Index for the reduction of the sludge quantity after dewatering	Observations
Dewatering units using solar energy and heat pumps	2400	1200	2	- the input mass flow determined by weighing; - the output mass flow determined by calculus, taking into account the reduction of humidity of the sludge from 18 % DS (measured after the chemical analyses of sludge) to 36 % DS, according to the design data.
Band dryer having as heat agent hot air and hot water	1200	665	1,8	- the mass flow output determined by calculus, taking into account the reduction of humidity of the sludge from 36 % DS to 65 % DS, estimated according to the domain literature, in order to ensure mono-combustion.
High efficiency burning installation	665	137	4,85	- the mass flow output results from the mineral percentage (including the phosphorous resulting from the wastewater treatment process) of the DS, determined after the chemical analyses of the sludge. - it is considered that, by burning, the volatile components are totally eliminated
The technological flux for thermal treatment of the sludge	2400	137	17,5	- the reduction of the sludge volume from the input of the technological flux up to the output is of 17,5 times.

4.2 Estimating the energetic balance of the sludge burning installation

The total efficiency of the cycle will be about 71,9 %, of which thermal efficiency of 39,6 % and an electric efficiency of 32,3 % [9].

Sludge mass flow input of the biomass combustor, m_{sludge} = 665 kg/h = 0,1847 kg/s.

The lower heat value of the sludge (determined by calculation), u_l = 7000 KJ/kg.

The available energy of the biomass combustor, $Q_{\text{in}} = m_{\text{fuel}} \cdot u_l$ = 1293 kW.

Total efficiency of the CHP, η_{CHP} = 71,9 %.

Electrical efficiency of the cycle, η_{el} = 32,3 %.

Thermal efficiency of the cycle, η_{th} = 39,6 %.

Power production of the plant layout (Power output) $P_{\text{Ge}} = Q_{\text{in}} \cdot \eta_{\text{el}}$ = 418 kW.

Heat production of the plant layout $Q_{\text{H}} = Q_{\text{in}} \cdot \eta_{\text{th}}$ = 512 kW.

Sludge mass flow input of the of the dryer, m_{dryer} = 1,200 kg/h.

Water evaporation capacity, m_{WVD} = 535 kg/h.

The thermal energy factor of the dryer HUBER Belt Dryer BTplus = 0,85 kW·h/kg WVD [8].

Thermal energy consumption of the dryer, when drying 1200 kg/h of 36 % DS to 65 % DS = 455 kW.

The electric energy factor of the dryer HUBER Belt Dryer BTplus = 0,06 kW·h/kg WVD [8].

Electric energy consumption of the dryer, when drying 1200 kg/h of 36 % DS to 65 % DS = 32 kW.

Electric energy available to operate the sewage sludge treatment plant = 386 kW.

The operating time of the plant layout = 7500 hours/year [8].

Electric energy available monthly to operate the sewage sludge treatment plant = 241 MW·h.

4.3 Results

After the energetic balance, the following observations can be made:

- The thermal and electrical energy obtained by cogeneration in sludge burning installations in thermodynamic cycles which are energetically efficient, based on the Pebble – Heater technology and hot air turbines fully cover the energy consumptions of the burning and sludge dewatering processes;
- There results a monthly supplementary gain of electrical energy of about 241 MW·h, which represents approx. 25 % of the total electrical energy consumption of the WWTP Timişoara;
- Depending on the electrical energy consumption of the installations from the sludge dewatering flux, upstream from the dryer, the electrical energy gain obtained might cover the entire consumption of the

sludge processing line; there may even be a surplus that can be used in the wastewater treatment process;

- The energy obtained by cogeneration within the sludge burning installation may increase with the increase of the calorific power, sludge biomass, which is possible by increasing the organic composition of the sludge;
- By implementing programmes for the calculation of the energetic balance one can optimise the components of the installation in view of increasing energetic efficiency.

5 Conclusions

The main advantages of the combustion or energy utilization of the sludge based thermodynamic cycles are:

- Electricity from sewage sludge saves fossil fuels and reduces fossil originated CO_2 emissions;
- One can make benefit of the green certificates offered by using sewage sludge as biomass, and finally selling them on the free market;
- The technology significantly reduces transport and storage costs for the owner of the water treatment plant;
- By implementing these thermodynamic cycles one can benefit by the full treatment sludge resulting from the water treatment process. Thus, bacteriological load with pathogen agents does not present any more risks for the use of residual ash in agriculture as dangerous bacteria and viruses are destroyed during the burning process;
- The amount of solid waste can be reduced by designing the ash to fit deposits, and/or recovery of incorporated phosphorus, thus being used as fertilizer for agriculture. Similarly one can store the heavy metals as well;
- The supplementary financial gains generated from electricity & heat selling – utilization for own purpose as well as the possibility to use the sludge as fertilizer for agriculture and bring significant economies by reducing transport costs, cover most cases of the cost of drying and burning sludge.

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6 References

[1] Neamt, I.; Ionel, I.; Florescu, C. Sewage Sludge to Energy. Possible strategies for Timisoara waste water treatment plant. // Chemisty Magazine, Iulie, Bucharest, 63, 7(2012), pp. 739-742.

[2] Alcani, M.; Dorri, A.; Hoxha, A. Management of municipal solid waste in Tirana: Problems and challenges. // Tehnički vjesnik-Technical Gazette, 17, 4(2010), pp. 545-551.

[3] Direcţia generală AM POS Mediu, Studiu făcut de consorţiul Mott Mac Donald în asociere cu ISPE, UTCB, BIOTEHNOL, Elaborarea politicii naţionale de gestionare a nămolurilor de epurare. Strategia naţionala de gestionare a nămolurilor, Partea a III-a (Final 2). Bucureşti, februarie 2012.

[4] Ministerul Mediului şi Gospodăririi Apelor Ministerul Agriculturii, Pădurilor şi Dezvoltării Rurale, Ordinul nr. 344 din 16 august 2004 pentru aprobarea Normelor tehnice privind protecţia mediului şi în special a solurilor, când se utilizează nămolurile de epurare în agricultură, Monitorul Oficial nr. 959, din 19.10.2004.

[5] European Commission, DG Environment under Study Contract, Final Report**,** Environmental, economic and social impacts of the use of sewage sludge on land**,** prepared by Milieu Ltd, WRc and RPA, DG ENV.G.4/ETU/2008/0076r.

[6] Vockrodt, S.; Leithner, R. Kombi-Anlage mit integrierter Klärschlamm-Verbrennung-CISCO (Combined Cycle with Integrated Sewage Sludge Combustion). // Journal "MÜLL und ABFALL", 12(2004), pp. 590-594.

[7] http://www.huber.de.

[8] http://www.huber.de/huber-report/ablage-berichte/sludge-treatment/sludge2energy-a-way-to-energy-autarkic-operation-of-sewage-treatment-plants.html

[9] Stevanovic, D. Innovative biomass power plant based on pebble-heater technology and hot air turbine, PowerGen 2001, Brussels, Belgium, 2001.

[10] Stevanovic, D.; Fafibinder, H.-G. Regenerative thermal oxidizers based on Pebble-Heater technology. // Proceedings of the 5th European Conference on Industrial Furnaces and Boilers, Volume 2, Porto, 11-14 April 2000, Portugal, INFUB, 2000.

[11] Jădaneanţ, M. Termotehnica şi mşini termice vol. I, II, Politehnica, Timişoara, 1990.

[12] Beitz, W.; Grote, K. H. Taschenbuch für den Maschinenbau 19 Auflage, Dubbel, Springer-Verlag GmbH, L8–L9, 1997.

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