Elsevier Editorial System(tm) for Renewable & Sustainable Energy Reviews
Manuscript Draft

Manuscript Number:

Title: Recovery of energy and material resources from sewage sludge and biomass residuals

Article Type: Review Article

Keywords: Solid recovered fuel, renewable energy sources, sewage sludge, environmental impact assessment, environmental indicators

Corresponding Author: Dr. Irina Kliopova, Dr.

Corresponding Author's Institution: Kaunas University of Technology (KTU)

First Author: Irina Kliopova, Dr.

Order of Authors: Irina Kliopova, Dr.; Kristina Makarskienė, Ms

Abstract: waste water treatment plant (Lithuania), including solid recovered fuel (SRF) production from the pre-composting materials: dewatering sewage sludge and biomass residuals. The evaluation was based on the research which was done when implementing one stage of the PF7 program project "Polygeneration of energy, fuels and fertilizers from biomass residues and sewage sludge (ENERCOM)". The laboratory analysis of different compost fractions shows that fraction 10-40 mm of pre-composted materials can be used for SRF production. The equipment for SRF production in a pellet form was developed in the compost production company "Soil-Concept" (Luxemburg).
Main chemical and physical parameters of SRF of pre-composted materials in both Lithuanian and Luxemburg pilot companies were compared. Carbon content amounts to higher than 37%. A net calorific value of SRF made of 10-40 mm fraction of pre-composted materials with about 15% of the moisture content is 12-15 MJ/kg. It corresponds to the net calorific value of the non-pressed sawdust with 30% of the moisture content.
The theoretical calculations of air emissions during SRF fluidized bed combustion (FBC) were carried out and emissions of specific pollutants were determined. Also the material and energy balance of sewage sludge processing, inc. SRF and compost production was formed and relative environmental indicators were evaluated. 82% of raw materials for SRF production are convertible to the energy. Finally, an economic evaluation of this new sewage sludge management methods was done. The implementation of the suggested sewage sludge processing method in Palanga waste water treatment plant will make it possible to minimize sewage sludge management cost price - by approx. 50%. The methodic and results of analyzes mentioned above as well as conclusions and recommendations are presented in this paper.

Suggested Reviewers: Jonas Motiejunas Dr.
Engineering Ecology Association
ekobaltas@gmail.com

Algirdas Raila Prof. dr.
Laboratory chemical and biochemical research for environmental technology , Institute of Environment of Aleksandras Stulginskis University
algirdas.raila@asu.lt

Professor has extensive experience in SRF production questions

Jurgis Staniškis academician
Prof., Kaunas Technological University
jurgis.staniskis@ktu.lt
He has an extensive knowledge of this subject

Opposed Reviewers: Gintaras Denafas Prof. dr.
Prof., Department of Environmental Engineering, Kaunas Technological University
gintaras.denafas@ktu.lt

Recovery of energy and material resources from sewage sludge and biomass residuals

Irina Kliopova[1], *Kristina Makarskienė*[2]

1Corresponding author. Kaunas University of Technology, Institute of Environmental Engineering, Vilnius department, Teatro str. 8 – 16, Vilnius, 03107 Lithuania. Tel./fax: +370-5-2649174, e-mail: irina.kliopova@ktu.lt

2Institute of Environmental Engineering, Kaunas University of Technology, Donelaičio str. 20, 44239 Kaunas, Lithuania. Tel. +370-616-03576, e-mail: kristina.makarskiene@gmail.com

Abstract

The paper presents the results of feasibility analysis of sewage sludge processing in Palanga waste water treatment plant (Lithuania), including solid recovered fuel (SRF) production from the pre-composting materials: dewatering sewage sludge and biomass residuals. The evaluation was based on the research which was done when implementing one stage of the PF7 program project “Polygeneration of energy, fuels and fertilizers from biomass residues and sewage sludge (ENERCOM)”. The laboratory analysis of different compost fractions shows that fraction 10-40 mm of pre-composted materials can be used for SRF production. The equipment for SRF production in a pellet form was developed in the compost production company “Soil-Concept” (Luxemburg).

Main chemical and physical parameters of SRF of pre-composted materials in both Lithuanian and Luxemburg pilot companies were compared. Carbon content amounts to higher than 37%. A net calorific value of SRF made of 10-40 mm fraction of pre-composted materials with about 15% of the moisture content is 12-15 MJ/kg. It corresponds to the net calorific value of the non-pressed sawdust with 30% of the moisture content.

The theoretical calculations of air emissions during SRF fluidized bed combustion (FBC) were carried out and emissions of specific pollutants were determined. Also the material and energy balance of sewage sludge processing, inc. SRF and compost production was formed and relative environmental indicators were evaluated. 82% of raw materials for SRF production are convertible to the energy. Finally, an economic evaluation of this new sewage sludge management methods was done. The implementation of the suggested sewage sludge processing method in Palanga waste water treatment plant will make it possible to minimize sewage sludge management cost price - by approx. 50%. The methodic and results of analyzes mentioned above as well as conclusions and recommendations are presented in this paper.

Key words

Solid recovered fuel, renewable energy sources, sewage sludge, environmental impact assessment, environmental indicators.

1. Introduction

The increasing demand of the primary energy on the one hand, and the shrinking reserve of the fossil fuel on the other hand induce the implementation of the energy saving solutions and the consumption of the renewable energy sources (RES) [1]. Energy production from RES is one of the major goals of EU Energy Policy, due to the high EU energy dependence rate -

an average 54% [2]. According to the data of the Statistics Lithuania, Lithuanian energy dependence rate is much higher – 79% [3].

There are plenty of the promotional mechanisms for the RES projects that are implemented in Lithuania. Many efforts have been taken for the maximum use biomass and wind energy. It is expected to employ energy potential from solid municipal waste such as landfill biogas, separating biodegradable fractions from solid municipal waste, and extracting biogas from fermentation process [4].

Biogas recovery during anaerobic processing of sewage sludge is one of the possibilities of RES. Produced alternative energy is used in waste water treatment plans or for farther sewage sludge treatment steps.

In Lithuania, sewage sludge after anaerobic treatment and dewatering in bigger towns (centers of regions) and after dewatering in other towns has been accumulated in the special storage sites yet [5]. It was concluded that after 300 days in a landfill the sludge is still in the process of degradation and maturity [6]. For the purpose of solving the problem of accumulation of sewage sludge in the special storage sites, currently, the possibilities to produce compost and/or solid recovered fuel (SRF) of dewatering sewage sludge are analyzed. Sewage sludge can serve as RES, since it is produced in the large amounts and has considerable energy content [7].

Unfortunately, the net calorific value of digested sewage sludge is lower than that of primary sludge [8] and [9]: up to 17.5 MJ/kg (in dry matter) – in primary sludge; up to 12 MJ/kg (in dry matter) – in sludge after fermentation.

During 2008-2012, the Institute of Environmental Engineering of Kaunas University of Technology (KTU APINI) participated in the FP7 program “Energy” project *“Polygeneration of energy, fuels and fertilizers from biomass residues and sewage sludge* (ENERCOM)” (No TREN/FP7/EN/218916). Project coordinator: Ifas - Institute for Applied Material Flow Management (Germany). The aim of the project was to demonstrate a highly-efficient poly-generation of the electricity, heat, solid fuels and high-value compost/ fertilizers from sewage sludge and greenery waste mixed with the biomass residues [10].

The compost production company, owned and operated by the consortium partner Soil-Concept in Luxemburg, was chosen as a pilot company. An aerobic treatment with the forced air supply methods is used for compost production of sewage sludge, greenery waste, and the biomass residues. One of the goals of the ENERCOM project was to assess the possibilities of producing SRF from the pre-composting of input materials: stabilized sewage sludge, municipal green waste (grass, branches, etc.) and bark. These input materials were mixed and pre-composed (i.e. biological drying) during approx. 3 weeks.

Then, the composite was separated by the fractions: <10 mm (up to 50% of total amount), 10-40 mm (approx. 40-45% of total amount), and >40%. Laboratory analysis of different fractions of pre-composted materials shows that fraction 10-40 mm can be used for SRF production [11]. Technical and environmental possibilities of producing SRF of various compositions of raw materials (pre-composted sewage sludge with municipal green waste, sawdust, peat, etc.) in the form of pellets and briquettes were analyzed by KTU APINI researchers with the technical assistance of several Lithuanian companies and ENERCOM project partners during 2008-2010. Results of that research have been already presented [12] and [13].

The several main results of the research are the following [13]:

- A net calorific value of SRF made of 10-40 mm fraction of pre-composted materials in the Soil – Concept company with 15% of the moisture content is 13-14 MJ/kg. It corresponds to the net calorific value of the non-pressed sawdust with 30% of the moisture content.
- The total energy consumption per unit of SRF in the pellet form production was evaluated, when applying environmental impact assessment (EIA) of the fuel

production - 0.526 kWh/kg, including 0.164 kWh/kg – for a pelletizing process.

- The amount of energy needed for the SRF production and combustion does not exceed that obtained during SRF combustion (23.6 MWh for 100 MWh of heat energy production).
- For the purpose of reducing an environmental impact on the air, pre-composted materials can be mixed with sawdust (up to 10% of the total SRF raw materials volume) or SRF can be burnt together with biofuel.

The evaluation of the possibilities of producing SRF from sewage sludge and biomass residues in Lithuanian waste water treatment plant was analyzed using the results of the ENERCOM project.

The analysis results are presented and discussed in this paper.

1.1 Description of pilot plant - Palanga waste water treatment plant

"Palangos vandenys" Ltd (pilot plant) is operating in Palanga town municipality (Palanga). Palanga is the biggest resort center in Lithuania. Population of 17.2 thousand people resides in a territory of approx. 8 thousand ha, which includes 33 % of forest area. More than 100 accommodation and food establishments are operating in Palanga. Yearly more than 500 thousand tourists visit this resort [14].

Generated sewage sludge is dewatered up to 20% of dry matter by mechanical press and accumulated in the special storage sites in the pilot company. An average amount of sewage sludge is 1500 tons or 1323 m^3/year. Since 1993 a big amount of sewage sludge (about 9 thousand tons) has been collected in the storage sites. Recently, the pilot company focuses on the sewage sludge delivering to a bigger sewage sludge treatment plant - JSC „Klaipėdos vanduo“, which is located about 35 km from Palanga. The total sewage sludge management cost is 84 €/ton.

Based on LAND 20-2005 (Lithuanian environmental normative document), the sewage sludge from Palanga waste water treatment plant is attributable to category I and II according to heavy metals content and to classes A and B according to microbiological-parasitological parameters [15].

For the purpose of solving the problem of sewage sludge accumulation within the pilot company, mixing of new dewatered sewage sludge (up to 1500 tons/year and 80% of the moisture content) and sewage sludge from storage sites (up to 1000 tons/year and 70% of the moisture content) with biomass residuals (green waste, collected from public territories in Palanga) (up to 2500 tons/year and an average 39% of the moisture content) and their pre-composting is suggested. The possibilities of SRF production from the separate fraction of pre-composted materials (10-40 mm) is analyzed below.

2. Methodology

The objective of this research was to assess whether SRF of pre-composted materials can be produced in the pilot plant and used for heat energy production in combustion plants. To achieve the objective the following tasks have been taken:

- To analyze chemical and physical characteristics of the sewage sludge in pilot plant;
- To evaluate chemical and physical characteristics of produced SRF of pre-composted materials in Lithuanian pilot plant in comparison to SRF in Luxemburg and other widely used in Lithuania RES, for example, wood sawdust;
- To analyze air emissions during produced SRF combustion;
- To form the material and energy balance of sewage sludge processing in the pilot company and to evaluate the relevant environmental indicators;
- To estimate whether the SRF production from sewage sludge and the biomass residuals is economically beneficial sewage sludge management method for pilot company.

The flow chart of SRF and compost production is presented in Figure 1.

Determination of main chemical and physical characteristics of sewage sludge, pre-composted materials, and separate fraction of pre-composted materials (10-40 mm) was carried out in the laboratory of Agrochemical Research in the centre of Lithuanian Agrarian and Forest Science. Evaluating results of the laboratory analysis were compared to the data of ENERCOM project [12] and [13] and to the recovered fuel classificatory [16].

In the second stage, it has been accepted that produced SRF is burnt using the grate fluidized bed combustion (FBC) technology in a combustion plant, thus efficiency – 85%. In case of sawdust burning, grate firing technology in a combustion plant with thermal power less than 30 tons/h and 95% of efficiency (due to condensing economizer) was applied [17]. For the purpose of comparing, in both case it has been accepted that 100 MWh of heat energy will be produced in these combustion plants.

Air emissions during sawdust burning (PM, CO, NOx) were evaluated using the methodology, which is written in the list of methodologies for the evaluation of air emissions, approved by the Ministry of Environment of the Republic of Lithuania (13-12-1999 No. 395, last addition in 2008) [18] and [17].

Since the methodology used in Lithuania for evaluation of air emission [18] does not include the factors and/ or coefficients for the FBC technology, air emissions were evaluated using data of SRF chemical composition and limited concentrations of air emissions under standard conditions [19], [20] and [13].

The actual concentration of air emissions (CO, $NO_{x,}$ PM, SO_2, HCl, heavy metals) is calculated by using the formula:

$$C^{fact} = C^{st} \cdot (21-O_2) / (21-O_2^{st}), \qquad (1)$$

where C^{fact} - actual concentration of pollutant, mg/Nm^3; O_2^{st} – oxygen concentration under standard conditions, 6%; O_2 – actual oxygen concentration in dry fume, %;

C^{st} - maximum air emission limit concentrations under standard conditions, mg/Nm^3 [21] and [22]: CO: 50-250 mg/Nm^3; NOx: 260-400 mg/Nm^3; PM: 20 - 50 mg/Nm^3; SO_2: 300 - 850 mg/Nm^3; HCl - < 25 mg/Nm^3; heavy metals:

- Σ (Sb, As, Pb, Cr, Co, Cu, Mn, Ni, V) – 0.5 mg/Nm^3;
- Σ (Cd, Ti) – 0.05 mg/Nm^3;
- Hg - 0.05 mg/Nm^3.

The actual oxygen O_2 concentration in dry fume is calculated by using the evaluated actual air excess coefficient [19] and [20].

Emissions of pollutants (CO, $NO_{x,}$ PM, SO_2, HCl, heavy metals) are calculated by the formula:

$$P = 0.001 \cdot C^{fakt} \cdot L_{d\ dry}, \text{ g/s}, \qquad (2)$$

where C^{fact} – actual concentration of pollutant, mg/Nm^3; $L_{d\ dry}$ – efficiency of exhauster or the actual dry fume flow (discharge), Nm^3/s.

The emission factors are determined by the formula:

$$P_{factor} = P/B, \text{ kg/ton}, \qquad (3)$$

where P – amount of the emitted pollutant, g/s; B – volume of burnt fuel, kg/s.

The volume of the fuel, burnt during the time unit, is calculated by the formula:

$$B = N/Q_n, \text{ kg/s}, \quad (4)$$

where N – boiler heat capacity, in case of experiment – 35 MW; Q_n – fuel lower calorific value, MJ/kg.

For the purpose of assessing the economical benefit of analyzed new sewage sludge management method, material and energy balances of sewage sludge processing and new products manufacturing were developed for each technological process: pre-composting, separation, 10-40 mm fraction of pre-composted materials drying, SRF production in pellets form (granulation), <10 mm fraction further composting, inc. maturation and compost production. Absolute environmental indicators (units/year) were evaluated for all material and energy flows and for the estimation of cost price of sewage sludge processing.

The relative environmental indicators (IE) of analyzed sewage sludge processing method were evaluated. EI are expected by units per ton of sewage sludge (unit/ton) and can be used for the evaluation of the environmental performance and comparison to other sewage sludge management methods [23].

3. Results and discussion

3.1 Chemical and physical characteristics of produced SRF

Physical and chemical characteristics of sewage sludge depend on the waste water composition and on sewage sludge treatment methods. Characteristics of the pre–composting materials are directly related to the variety of compost composition (green waste, sewage sludge, etc). As in case of Luxemburg compost production company, SRF in Palanga pilot plant was produced of 10-40 mm fraction of the pre-composted materials (about 50% of dewatering sewage sludge and 50% of green waste). Table 2 presents the information about chemical characteristics of pre–composted materials (10-40 mm fraction) in pilot plant in comparison to pre–composted materials in Luxemburg, and sawdust.

Carbon content in dry matter of the pre-composted materials in case of Palanga pilot plant amounts to higher than 37%; it is only about 15% lower than the carbon content in sawdust. Ash content in dry matter of the pre-composted materials in Palanga pilot plant amounts to higher than 20%; it is more than 20 times higher compared to the sawdust ash content, which is very low - 1%, but is 1.5 times lower than the ash content of the pre-composted materials in Luxemburg compost production company. The sulphur and chlorine content in dry matter of the pre-composted materials in case of Palanga pilot plant is lower than in case of Luxemburg compost production company.

Obviously, the pre-composted materials produce the highest chlorine, sulphur, nitrogen, heavy metals content compared to the sawdust. It can be noted that content of heavy metals in case of Palanga pilot plant is about 1.6 times lower than in case of Luxemburg compost production company. Most of heavy metals are emitted in the compounds with dust. Therefore, high efficiency dust collectors, as electrostatic precipitators or fabric filters, are widely used to reduce the volume of heavy metals.

Evaluating results of the laboratory analysis, the SRF was compared to the standard requirements for SRF according to CEN/TC 343. The comparison shows that both SRF corresponds to the standard requirements for the recovered fuel [24] (see Table 3).

3.2 Evaluation of air emissions during SRF combustion

The amount of SRF for 100 MWh of the heat energy production in combustion plants with 35 MW of capacity and 85% of efficiency is 29.721 tons. Applying the methodology (see formulas 1-4), air emissions during SRF fluidized bed combustion (FBC) and air emissions factors were calculated and results are presented (see Table 4).

The volume of air emissions during 100 MWh of the heat energy production, burning SRF in comparison to sawdust is presented in Table 5.

3.3 Results of environmental evaluation of sewage sludge processing and SRF production

Applying the relative environmental indicators of SRF production, estimated during monitoring of the pelleting process in Luxemburg [25] and [13], technical characteristics of compost turner, separator and dryer, the material and energy flows diagram of the SRF and compost production was formed in Figure 2.

The main parameters of the composting process were taken in to account during the technical assessment: temperature (increases from 15 to 75 ^oC), optimal volume of moisture content (50-60%), optimal volume of oxygen content (15-20%), optimal volume C:N ratio (20-30:1), optimal pH volume (6-8), etc. The implementation of traditional open composting system was evaluated.

The moisture content of the input materials is approx. 57-60% (see Figure 2). The pre-composting continues approx. 3 weeks. During whole composting process (inc. maturation), the mass of the input materials is double decreased (e.g. 80% – due to water evaporation and 20% – due to losses of dry materials). Abut 20% of waste water will be reused for the composting process; other part must be supplied to the waste water treatment plant.

As was monitored during ENERCOM project, a fair amount of metal waste and other solid additives could be found in pre-composted materials: up to 0.021 kg/kg of produced pellet [12]. Therefore, it is necessary to remove stones, metal waste, wood parts (>20 mm), etc, which could damage technological lines.

The relative environmental indicators of analyzed sewage sludge processing method were evaluated and presented in Table 6. Total amount of energy for the processing of 1 ton of sewage sludge is 162.2 kWh, total air emissions – 0.0192 ton/ton. Volume of produced SRF makes 20% of the total mass of input raw materials; volume of produced compost makes approx. 23% of input raw materials.

The energy balance of the SRF production and combustion for 100 MWh of the heat energy production in comparison to sawdust combustion is presented in Table 7. The amount of energy in case of SRF production and burning it for the purpose of producing 100 MWh of the heat energy is more than 7 times higher compared to the sawdust burning. The total amount of energy needed for the SRF production (inc. energy for pre-composting, separation, drying, granulation, etc.) is approx. 6.5 times less then obtained during SRF combustion: 0.155 MWh/MWh. That is approx. 30% less than it was received in ENERCOM project [13]. More then 50% of total energy is used for pre-composted materials drying from 37 to 15% of the moisture content.

Energy consumption per unit of production is a very important environmental indicator. Evaluating energy consumption per unit of recovered fuel production (kWh/kg), it can be concluded that pre-composted materials drying process is considerably more energy-intensive than pelleting process. Total energy consumption for 1 kg of SRF production is 0.459 kWh/kg, inc.

- 0.015 kWh – consumption of diesel fuel for green waste transportation, for pre-composting, screening, loading, etc.;
- 0.280 kWh – natural gas consumption for drying of the pre-composted materials,
- 0.164 kWh – for pellets production.

Exactly, the moisture content of pre-composted materials is decreased by 35-38% during the pre-composting process (approx. 3 weeks) with minimum energy (diesel fuel) consumption for compost turner, separation and loading processes.

3.4 Results of economical evaluation of the new method of sewage sludge processing

The direct sewage sludge processing costs were evaluated using material and energy balance in Figure 2. An operating cost of sewage sludge processing consists of direct cost, personnel cost, the cost of laboratory analysis of manufactured product (SRF and compost), the cost of equipment maintenance, and insurance (see Table 8).

The implementation of the suggested sewage sludge processing method will make it possible to minimize sewage sludge management cost price in the pilot plant by approx. 50% and save about 82 thousand €/year (see Table 8). The estimated income from the SRF sale will be about 50 thousand €/year, from compost sale - about 20 thousand €/year.

Total project investment (loader, compost turner, screening equipment (trommelscreen), including designing works, hangar building for compost maturation, pellets production press) is approximately 610 thousand €. The project payback period is approximately 7.4 years.

4. Conclusions

As seen from the ENERCOM project, such environmental questions as biodegradable waste management and RES are related and can be solved simultaneously, for example, SRF can be produced from 10-40 mm fraction of the pre-composted sewage sludge and biomass residues.

Certain results of ENERCOM project were applied for the evaluation of the new possibilities of sewage sludge management in Lithuanian waste water treatment plan "Palangos vandenys" Ltd. (pilot plant), where approximately

1500 tons/year of dewatering sewage sludge are generated (with 80% of the moisture content), and about 9000 tons of old sewage sludge are collected in the special sites. Currently, dewatering sewage sludge is accumulated in these sites and / or delivered to bigger waste water treatment plant for anaerobic treatment.

The implementation of compost and SRF production of sewage sludge and the same volume of biomass residues was suggested for the pilot company. Characteristics of raw material for SRF production were improved after pre-composting (during approx. 3 weeks). First of all, the moisture content is decreased by 38%. Besides, the amount of ash and metals in the pre-composted materials decreases significantly. Carbon content in these composite increases by approximately 50% compared to sewage sludge.

Evaluating results of the laboratory analysis, the produced SRF was compared to the standard requirements for SRF according to CEN/TC 343. The comparison shows that produced SRF of pre-composted materials (fraction - 10-40 mm) in the pellet form corresponds to class 4 by the net calorific value (14.25 MJ/kg), class 1 by the chlorine content in dry matter (0.016%), and class 2 by the mercury content (0.042 mg/MJ).

In order to optimize heat energy production process and to reduce the environmental impact during SRF burning, complex combustion technologies (for example, in case of experiment - FBC) have to be applied and, in terms of economical return, they are usually recommended to large fuel combustion plants (for example, in case of experiment – 35 MW).

When applying EIA for the sewage sludge processing, SRF production and combustion, the total energy consumption was evaluated:

- per unit of processed sewage sludge - 162.2 kWh/ton;
- per unit of produced SRF– 0.459 kWh/kg;
- the amount of total energy needed for the SRF pellets production and its combustion for 100 MWh of heat energy production is 15.5 MWh.

Positive aspects of EIA of SRF production and combustion are the following:

- 82% of raw materials for SRF production are convertible to the energy; only 18% of mass becomes waste (ash, bottom ash, and production losses);
- the volume of CO_2 emitted during SRF combustion equates zero due to biogenic nature of raw materials used in SRF production;
- in case of applying suitable combustion technologies and PM removal techniques, the volume of air emissions during energy production burning SRF of pre-composted materials can be lower than the air emissions during sawdust burning.

The implementation of the suggested sewage sludge processing method in the pilot company will make it possible to minimize amount of waste by 98%, sewage sludge management cost price - by approx. 50%. The project payback period is approximately 7.4 years.

Produced compost will be used for the fertilization of park and energy plants areas in Palanga. SRF will be realized as an alternative fuel to nearest combustion plants, for example, "Fortum Klaipėda" Ltd. (a combined heat and power station with biofuel combustion and waste incineration plant).

The results of this study show that the new method of sewage sludge management presented in this paper can be used in municipal waste water treatment plants as an alternative way of sewage sludge and green waste processing with economical and environmental benefits.

Appendices

Table 1. Sludge categorization of heavy metal concentration.

Table 2. Evaluated characteristics of pre-composted materials in comparison to sawdust.

Table 3. Comparison of SRF of pre-composted materials with the classification system of SRF (CEN/TC 343).

Table 4. Emissions of specific pollutant, when burning SRF (FBC), kg/ton.

Table 5. Results of theoretical calculation of air emissions burning SRF of pre-composted materials and sawdust for 100 MWh of the heat energy production, ton.

Table 6. Relative environmental indicators (EI) of sewage sludge processing.

Table 7. Comparison table: energy balance of fuels (SRF of pre-composting materials, and sawdust) production and combustion for 100 MWh of the heat energy production.

Table 8. Main results of economical evaluation of new sewage sludge processing method in comparison to existing (results for the pilot plant)

Figure 1. SRF and compost production flow chart.

Figure 2. Processing of sewage sludge from “Palangos vandenys” Ltd. and green waste from Palanga (flow diagram).

References

[1] Cao Y, Pawlowski A. Sewage sludge-to-energy approaches based on anaerobic digestion and pyrolysis: Brief overview and energy efficiency assessment. Renew. Sustainable Energy Rev. 2012; 16:1657-1665.

[2] Eurostat newsrelease. 23/2013. Available from: http://epp.eurostat.ec.europa.eu/cache/ITY_PUBLIC/8-13022013-BP/EN/8-13022013-BP-EN.PDF [accessed 29/05/2013].

[3] Statistics Lithuania. Available from: http://web.stat.gov.lt/lt/news/view/?id=9044&PHPSESSID=twmjcujxideyz [accessed 29/05/2013].

[4] LITBIOMA, 2008. Lithuanian renewable energy resources promotion action plan for 2010-2020. Applied research work [in Lithuanian]. Available from: http://www.ena.lt/doc_atsi/Atsi_EI.pdf [accessed 02/05/2013].

[5] Report of Environmental Protection Agency (EPA), 2010-2012. Public information due to waste water and sewage sludge management according to the Article 16 of the Council Directive 91/271/EEC concerning urban waste-water treatment (21st of May 1991).

[6] Zhu Y, Zhao Y. Stabilization process within a sewage sludge landfill determined through both particle size distribution and content of humic substances as well as by FT-IR analysis. Waste Manag Res 2011; 29:379-385.

[7] Cao Y, Pawlowski A. Life cycle assessment of two emerging sewage sludge-to-energy systems: Evaluating energy and greenhouse gas emissions implication. Bioresour Technol 2013; 127:81-91.

[8] Wetle S, Wilk R. A review of methods for the thermal utilization of sewage sludge: the Polish perspective. Renew Energy 2010; 35:1914-1919.

[9] Houdkova L, Boran J, Ucekaj V, Elsaber T. and Stehlik, P. Thermal processing of sewage sludge—II. Appl. Therm. Eng. 2008; 28:2083–2088.

[10] ENERCOM, 2008-2013. Summary and objectives of Collaborative project Polygeneration of energy, fuels and fertilizers from biomass residues and sewage sludge. http://www.enercom.stoffstrom.org [accessed 15/05/2013].

[11] Obernberger I, Brunner T, Polzer A. Generation of raw materials: report on input fuel analysis. Publishable summary. ENERCOM. BIOS. 2009.

[12] Kliopova I, Makarskienė K. Generation of Solid Recovered Fuel from Sewage Sludge Compost. Environ. Res. Eng. Manage. 2012; 4(62):39-52.

[13] Kliopova I, Makarskienė K. Generation of solid recovered fuel from the separate fraction of pre-composted materials (sewage sludge and biomass residues). Environ. Res. Eng. Manage. 2013; 2(64): 5-8.

[14] Statistics Lithuania. Database of indicators, 2013. Available from: http://db1.stat.gov.lt [accessed 29/05/2013].

[15] Ministry of Environmental of the Republic of Lithuanian, 2005. Requirement of sewage sludge usage for fertilization and restoration LAND 20-2005 (last addition – 2012 No. D1-76).

[16] European Committee for Standardization (ed.), 2011. Solid recovered fuels - Specifications and classes. Technical Committee 343 Solid Recovered Fuels (CEN TC 343). CEN/TR 15359:2011.

[17] Staniškis JK, Stasiškienė Ž, Kliopova I, Varžinskas V. Sustainable innovations in Lithuanian Industry: Development and Implementation. Kaunas: Technologija; 2010.

[18] Set of methods for the calculation of air emissions from the different production process (1986, last addition – in 2000). Evaluation of air emissions burning different fuel in combustion plants with capacity less than 30 t/h. Publisher Gostkomgidromet, Leningrad [in Russian].

[19] Gimbutis G, Kajutis K. Thermal techniques. Educational book. Kaunas: Mokslas;1983.

[20] Denafas G. Atmosphere protection (part I). Results of air pollutions and control. Educational book. Kaunas: Technologija; 2000.

[21] Directive 2000/76/EC of the European Parliament and of the Council of 4 December 2000 on the incineration of waste.

[22] European Commission, 2006. Integrated Pollution Prevention and Control. Reference Document on Best Available Techniques for Large Combustion Plants. Available from:

<http://193.219.133.6/aaa/Tipk/tipk200702/dideli%20kura%20deginantys%20irenginiai%20%28en%29.pdf> [accessed 08/04/2013].

[23] Kliopova I, Staniškis JK, Petraškienė V. Solid recovered fuel production from biodegradable waste in grain processing industry. Waste Manag Res 2013; 31(4): 384-392.

[24] European Committee for Standardization (ed.), 2006. Key properties on solid recovered fuels to be used for establishing a classification system. Technical Committee 343 Solid Recovered Fuels (CEN TC 343), CEN/TR 15508:2006.

[25] Soil-Concept, KTU APINI. Generation of fuel: pelleting press monitoring report. Publishable summary. ENERCOM. 2010.

Figure

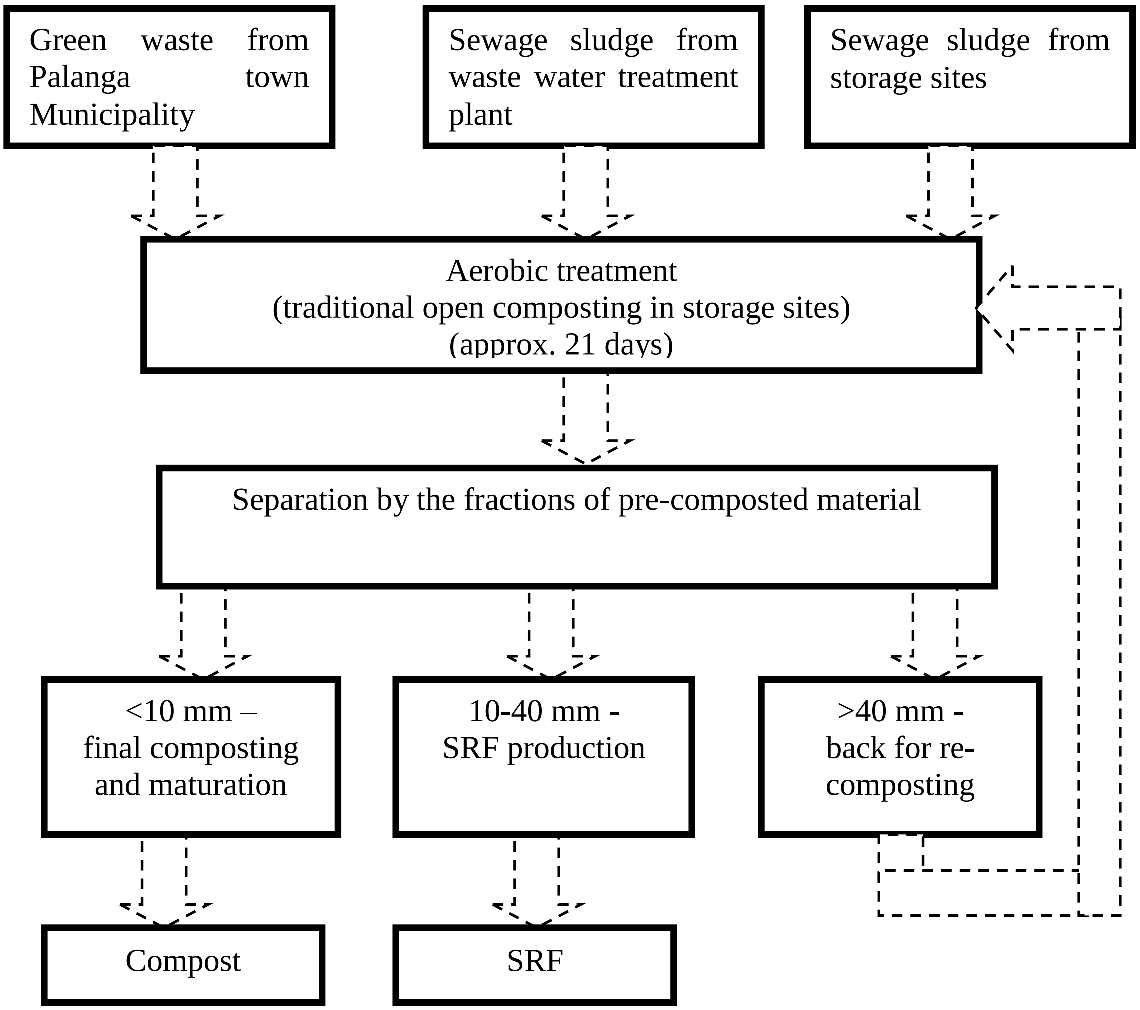

Figure 1. SRF and compost production flow chart.

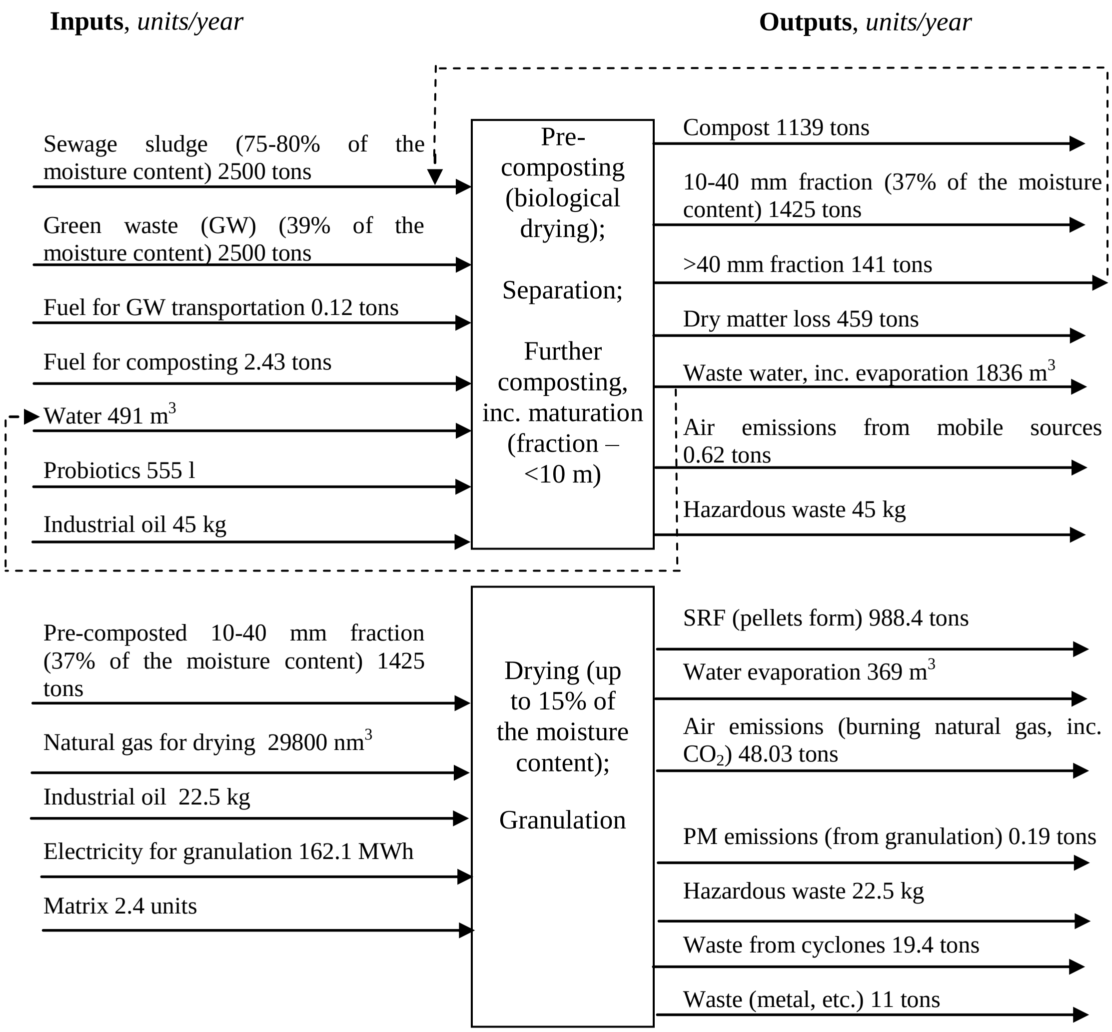

Figure 2. Processing of sewage sludge from “Palangos vandenys” Ltd. and green waste from Palanga (flow diagram).

Table

Table 1. Sludge categorization of heavy metal concentration.

Categories of sewage sludge	Heavy metal content, mg/kg of dry matter						
	Pb	Cd	Cr	Cu	Ni	Zn	Hg
I category	15-24 (<140)		18-24 (<140)		12-23 (<50)		0.2-0.4 (<1.0)
II category		1-4 (1.5–20)		100-125 (75– 1000)		800-1000 (300–2500)	

Table 2. Evaluated characteristics of pre-composted materials in comparison to sawdust.

Analyzed parameters	Content of chemicals in dry matter, %		
	[1]Pre – composted materials in Luxemburg	[2]Pre – composted materials in Palanga	[3]Sawdust
Ash content	30.770	20.570	1.000
Hydrogen (H)	4.340	4.580	5.400
Carbon (C)	36.320	37.380	43.760
Nitrogen (N)	1.860	2.040	0.500
Sulphur (S)	0.573	0.430	0.042
Chlorine (Cl)	0.138	0.016	0.007
Cadmium (Cd)	1.000×10^{-4}	1.100×10^{-4}	0.400×10^{-4}
Copper (Cu)	0.012	0.013	1.000×10^{-3}
Lead (Pb)	3×10^{-3}	1.500×10^{-3}	0.300×10^{-3}
Nickel (Ni)	5×10^{-3}	0.490×10^{-3}	0.001
Chromium (Cr)	0.009	0.001	0.001
Hydrargyrum (Hg)	0.120×10^{-3}	0.070×10^{-3}	0.020×10^{-5}
Zinc (Zn)	0.065	0.044	0.002
Manganese (Mn)	0.052	0.045	0.003
Iron (Fe)	1.070	0.570	0.757
Calcium (Ca)	2.580	3.630	0.470
Aluminium (Al)	1.760	0.610	0.378

1 10-40 mm fraction of pre-composted materials (about 50% of digested and dewatering sewage sludge, about 26% of green waste, and other biomass residuals) [11,25];

2 10-40 mm fraction of pre-composted materials (about 50% of dewatering sewage sludge, about 50% of green waste of Palanga town municipality);

3 Sawdust: 30% of deciduous trees sawdust and 70% of softwood.

Table 3. Comparison of SRF of pre-composted materials with the classification system of SRF (CEN/TC 343).

	SRF of pre-composted materials in Palanga (10-40 mm fraction)		SRF of pre-composted materials in Luxemburg (10-40 mm fraction)	
	value	class	value	class
SRF form	pellets		pellets	
[1]Net calorific value as receives, MJ/kg	14.25	4 (≥10)	13.73	4 (≥10)
Chlorine (Cl) content in dry matter, %	0.016	1 (≤0.2)	0.138	1 (≤0.2)
Hydrargyrum (Hg) content, mg/MJ (median)	0.042	2 (≤0.06)	0.084	4 (≤0.15)

1 Moisture content: in case of Palanga - 15%; in case of Luxemburg – 12%.

Table 4. Emissions of specific pollutant, when burning SRF (FBC), kg/ton.

Evaluated emissions	[1]C^{fact}	[2]P	[3]P_{factor}
	mg/Nm^3	g/s	kg/ton
Carbon monoxide (CO)	84.883	1.886	0.781
Nitrogen oxides (NOx)	226.354	5.030	2.083
Dust (PM)	28.294	0.629	0.26
Sulphur oxides (SO_2)	481.001	10.688	4.427
Heavy metals:			
Σ (Sb, As, Pb, Cr, Co, Cu, Mn, Ni,V)	0.280	0.006	0.0025
Σ (Cd, Ti)	0.030	0.001	0.0002
Hg	0.030	0.001	0.0002

1 Cfact – actual concentration of the pollutant, mg/Nm3 (under Formula 1);

2 P – amount of the pollutant emitted, g/s (under Formula 2);

3 P factor - factor of air emission, kg/ton of burnt SRF (under Formula 3).

Table 5. Results of theoretical calculation of air emissions burning SRF of pre-composted materials and sawdust for 100 MWh of the heat energy production, ton.

Fuel type	[1]Fuel volume, ton	CO	SO_2	NOx	HCl	[2]PM	Heavy metals
Wood sawdust (Kliopova and Makarskienė, 2013)	31.600	0.372	0.023	0.046	0.002	0.002	$0.800x10^{-4}$
SRF (Palanga)	29.721	0.023	0.130	0.061	0.003	0.008	$0.910x10^{-4}$

1 Combustion methods: grate firing technology – in case of sawdust, FBC – in case of SRF;

2 Efficiency of fly ash removable systems: 98.5% - in case of sawdust burning (due to double treatment: with multi-cyclone and condensate economizer); 99.5% - in case of electrostatic filter.

Table 6. Relative environmental indicators (EI) of sewage sludge processing.

Inputs and flows of sewage sludge processing	Dimension	Relative EI units/ton of sewage sludge
Inputs		
Sewage sludge	ton	1.000
Green waste	ton	1.000
Probiotics	l	0.222
Fuel (diesel)	tons	0.001
Natural gas	nm^3	11.92
Electricity	MWh	0.065
Industrial oil	kg	0.027
Outputs		
Compost	ton	0.456
SRF	ton	0.395
Dry matter loss (air emissions, etc.)	ton	0.184
Water lost (waste water and evaporation)	m^3	0.901
Air emissions from mobile sources	ton	0.0002
Air emissions from stationary sources	ton	0.019
Waste (metal, from filters, etc.)	ton	0.012

Table 7. Comparison table: energy balance of fuels (SRF of pre-composting materials, and sawdust) production and combustion for 100 MWh of the heat energy production.

	Dimen-sions	100 MWh of the heat energy production, burning	
		Sawdust [13]	SRF pellets
Fuel characteristics:			
Moisture content	%	50	15
Fuel lower calorific value	MJ/kg	12	14.25
Volume for 100 MWh of the heat energy production	tons	31.600	29.721
Main characteristics of combustion plants:			
Capacity	MW	<35	35
Efficiency	%	95	85
Technology		grate firing with condenser economizer	FBC
Main inputs:		Sawdust	Pre-composted materials
Raw materials moisture content before drying	%	50	37
Raw materials for fuel production:			
Before drying	tons	31.600	42.849
After drying	tons	31.600	31.754
Heat consumption for raw material drying	nm^3 (MWh)	-	896.08 (8.336)
Electricity consumption for the main technological process (pressing)	MWh	-	4.874 (0.164 kWh/kg)
Electricity consumption in combustion plant (in case of sawdust – in combustion plant, and in economizer)	MWh	1.9 (18.74 kWh/MWh)	1.8 (18 kWh/MWh)
Diesel fuel consumption, e.g. for pre-composted materials mixing, compost turner, screening, compost and fuel loading	MWh	0.2	0.456
Total energy consumption:	**MWh**	**2.100**	**15.466**
Main outputs:			
Heat energy production	**MWh**	**100**	**100**
Heat energy losses during production	MWh	5.33	17.65

Table 8. Main results of economical evaluation of new sewage sludge processing method in comparison to existing (results for the pilot plant)

	Sewage sludge delivery to the waste water treatment plant JSC „Klaipėdos vanduo“	Sewage sludge processing within the pilot plant (SRF and compost production)
Amount of processing sewage sludge	1500 tons/year	2500 tons/year
[1]Operating costs	125,115 €/year	113,272 €/year
[2]Income from compost sale	-	20,456 €/year
[3] Income from SRF sale	-	49,420 €/year
[1]Cost price of sewage sludge		43,396 €/year
management	125,115 €/year	17.36 €/year
[4]Cost price of sewage sludge	83.41 €/year	104,361 €/year
management, inc. amortization		41.74 €/year

1 Without equipment amortization cost;

2 Compost price: 17.96 €/ton (under the contract with Municipality);

3 SRF price: 41-58 € (an average market price);

4 Evaluating the cost of equipment amortization (an average amortization period – 10 years).

Cover letter

The novelty of this work

Sewage sludge production differentiated significantly among various countries in the EU, for example, in Lithuania - approx. 28 kg/capita/year of dry solids (DS). Biogas recovery from a waste water treatment plant by means of anaerobic processing of sewage sludge is one of widely applied sewage sludge processing methods. Extracted biogas is used in cogeneration plants for energy production. Produced energy is used for farther sewage sludge treatment. The volume of sewage sludge after anaerobic treatment could increase. The question for today in Lithuania and other EU courtiers is what to do with digested sewage sludge. Some of the waste water treatment plants analyze the possibilities to produce solid recovered fuel (SRF) from dried sewage sludge. Unfortunately, the net calorific value of sewage sludge is rather low: digested – up to 12.0 MJ/kg (in dry matter), primary up to 17.5 MJ/kg (in dry matter). Moreover, a lot of additional energy is used for sludge drying. It is suggested to utilize the sewage sludge by mixing it together with other properly selected wastes, i.e. with under-grade sized coal, with waste from animal waste utilization plants, etc.

In many countries digested sewage sludge after anaerobic treatment is used for the compost production. Different composting technologies are developed for the purpose of optimizing the composting process and reducing the environmental impact. Sewage sludge is mixed with biomass residuals for improving the process and the quality of produced compost.

The paper presents the results of the research, which was done when implementing one stage of the FP7 program project "Polygeneration of energy, fuels, and fertilizers from biomass residues and sewage sludge (ENERCOM)" – the study on peat and / or sawdust substitution potential for the solid recovered fuel (SRF) of compost. The compost is produced of pre-treated sewage sludge and biomass residuals in a "Soil-Concept" plant (Luxemburg). During ENERCOM project implementation, the laboratory analysis of different compost and pre-composted materials fractions shows that fraction 10-40 mm of pre-composted materials can be used for SRF production, <10 mm – for further compost production. The equipment for SRF production in a pellet form was developed in "Soil-Concept". Pelleting press monitoring was carried out to evaluate real environmental indicators (EI) and to optimize process.

The results of this stage of ENERCOM project were applied for the evaluation of new sewage sludge management possibilities in Palanga town municipality (one of the several case studies of RECO Baltic 21 Tech project). Palanga is the biggest resort center in Lithuania on the shore of the Baltic Sea. In Palanga as in the whole Lithuania, the sewage sludge characterizes less volume of heavy metals and other hazardous elements (in comparison to EU average). Therefore, the implementation of analyzed method will allow contributing to the solution of several environmental questions:

- Extraction of energy resources from waste (produced SRF - renewable energy sources);
- Extraction of materials from waste (produced compost can be used for the fertilization of parks and energy plants areas);
- Minimization of environmental impact of sewage sludge processing with economical benefits (the implementation of the suggested sewage sludge processing method in Palanga waste water treatment plant will make it possible to minimize amount of waste by 98%, sewage sludge management cost price - by approx. 50%).