Environment Protection Engineering

Vol. 39 2013 No. 2

DOI: 10.5277/EPE130214

RYSZARD WASIELEWSKI[1], SŁAWOMIR STELMACH[1], BARBARA JAGUSTYN[1]

SEWAGE SLUDGE AS A RENEWABLE ENERGY CARRIER AND CO_2 ZERO EMISSION BIOMASS IN CO-COMBUSTION WITH COAL

Sewage sludge management in Poland is a major environmental problem. The preferred solution to this problem may be co-combustion of sludge with coal in existing power plants. The paper presents the current legal basis and the benefits associated with the recognition of sewage sludge as renewable energy carrier and biomass with zero CO_2 emission factor in the processes of coal co-combustion. Energy parameters of sewage sludge resulting from its organic fraction, which is mostly biodegradable material, have been characterized. The results of investigation of the biodegradable fraction content in sewage sludge by the method of selective dissolution have also been presented.

1. INTRODUCTION

National Waste Management Plan anticipates that, in 2022 Poland will produce approximately 750 thousand tons dry weight of municipal sewage sludge [1]. At present, energy production from sewage sludge is increasingly being used because the potential of agricultural use and landfilling of these wastes are limited. Reasonable option of the sewage sludge management may be their co-combustion with coal in existing power plants. Co-combustion of sewage sludge is realized in Western Europe in many power plants – especially in Germany, but also in Belgium, the Netherlands, and Austria [2, 3]. German power plants which co-firing sewage sludge with coal are located e.g. in Duisburg, Heilbronn and Weiher (hard coal) and Berrenrath, Boxberg and Lippendorf (brown coal) [4, 5]. Overall in Germany, co-combustion of sewage sludge in power industry is carried out in eighteen hard coal-fired power plants and eight brown coal-fired power plants [5]. The weight fraction of sewage sludge in fuel

[1]Institute for Chemical Processing of Coal, ul. Zamkowa 1, 41-803 Zabrze, Poland; corresponding author R. Wasielewski, e-mail: rywas@ichpw.zabrze.pl

mixture usually does not exceed 10%. Analyzing the available operating data, it can be stated that there have been no significant deviations in these power facilities in the functioning of the boiler compared to the operation using only coal. A slight increase in emissions of certain gaseous substances was observed and the increase of heavy metals content in fly ash.

At present, no co-combustion of sewage sludge with coal in power plants in Poland is employed, however preliminary trials are undertaken to enable a technical assessment of such a solution. This is mainly due to the law because based on the experience of other countries it can be stated that from the technical point of view co-combustion does not cause any significant problems. It may even provide additional benefits. Sewage sludge is biodegradable waste. This fact can provide enterprises which take into account the possibility of sludge co-combustion, additional advantages associated to qualifying of energy produced to the so called green energy as well as accounting of carbon dioxide emissions [6, 7].

2. BASIC TECHNICAL REQUIREMENTS FOR CO-COMBUSTION OF SEWAGE SLUDGE

The most important technical requirements to be met at co-combustion of sewage sludge with coal, result from the binding legal acts. The process of co-combustion of municipal sewage sludge with coal is a process of waste incineration. Industrial installation in which this process occurs becomes an installation of waste co-combustion, which automatically causes legal consequences [8]. Co-combustion of sewage sludge should be conducted in accordance with the requirements of the Ordinance by Minister of Economy and Labour of 21 March 2002 on the requirements for conducting the process of wastes thermal treatment [9]. This means that the process of co-combustion shall be carried out in such a way that the temperature of the gases generated, measured near the inner wall or at another representative point of the combustion chamber, which results from technical specification of installations, even under the most adverse conditions, was raised in a controlled and homogeneous manner and was maintained for at least 2 s at the level not lower than 850 °C for waste containing less than 1% of halogenated organic compounds converted to chlorine (chlorine content in municipal sewage sludge is lower than 1% therefore the condition for maintaining flue gases temperature >1100 °C for at least 2 s during sewage sludge co-combustion is not applicable).

The total organic carbon content of slag and ash should not exceed 3%, or share of combustible parts of slag and fly ash should not exceed 5%. Furthermore, the co-combustion installation must be equipped with an automatic waste feed system allowing one to stop feeding:

- at the starting point, before reaching required temperature,
- during the process, if required temperature is not reached, or emission limit values are exceeded.

The installation should also have a system of continuous measurement of temperature, oxygen content and pressure of flue gases in the combustion chamber or in the final combustion chamber.

The entity for co-combustion of sewage sludge with coal is responsible for carrying out measurements of emissions in accordance with the requirements of the Ordinance by Minister of Environment of 4 November 2008 on the requirements for emission measurements and measuring quantities of received water [10]. Range and the reference methodology for execution of continuous and periodic measurements of emissions to air from wastes co-combustion installation are contained in Appendix 3 to this Ordinance. In accordance with the guidelines contained in Appendix 3 continuous measurements of emissions during co-combustion of wastes (for installations with a total thermal power not lower than 100 MW) should include: total dust, SO_2, NO_x (expressed as NO_2) CO, HCl, organic substances in the form of gases and vapours, expressed as total organic carbon, HF, O_2 and also the flow velocity or dynamic pressure of gases, their temperature, static or absolute pressure, and absolute humidity or moisture content. Periodic measurements should include emission of Pb, Cr, Cu, Mn, Ni, As, Cd, Hg, Tl, Sb, V, Co, dioxins and furans.

For entities conducting co-combustion of wastes very important is the Ordinance of The Minister Environment of 22 April 2011 on emission standards from installations [11]. In this Ordinance, Chapter 3, § 16, p. 2 provides that if in the installation fossil fuels are combusted with non-hazardous waste in an amount not higher than 1 wt. % of these fuels, provisions contained in this chapter are not applicable to this installation. In practice, this means the need to apply for such facilities previously used emission standards for fuels which were so far burned. In the case of exceeding 1 wt. % of sewage sludge in the fuel mixture, much stricter emission standards apply, determined by the so-called mixing rule described in Annex 6 to this Ordinance. Emission standards set by Annex 6 are difficult to be kept for many existing power plants. At the same time, regulation concerning co-incineration of waste in the amount to 1 wt. %, absolutely do not exempt from the obligation to apply other regulations, particularly with respect to the gas residence time at a given temperature and content of combustibles in the ash.

3. SEWAGE SLUDGE AS BIOMASS

In the national legislation, currently there are several definitions of biomass, important for the possibilities of using it in power engineering. These definitions are different from each other in details and are used for various purposes, inter alia to the compliance of responsibilities of environmental protection regulations during energetic use of biodegradable materials, as well as to settlement of the share of energy from renewable sources and for monitoring and settlement of carbon dioxide emissions, and in accordance with these objectives shall be applied. The definition of biomass contained in Ordinance by the Minister of Economy and Labour on 23 February 2010 amending Ordinance on the detailed scope of responsibilities to obtain and submit for redemption the certificates of origin, pay the replacement fee, purchase of electricity and heat produced of renewable energy sources and the obligation to confirm the data on the amount of electricity generated of renewable energy source, indicating biodegradable wastes, as one of its representatives, enables also classifying to this group, any other types of biodegradable wastes, such as municipal sewage sludge [12]. This is possible on condition that the recovery of energy from these types of biomass will take place according to the rules that apply to processes of waste thermal conversion. Provisions consequential to the Directive 2000/76/EC on the incineration of waste apply in this case.

In Part F of Annex 1 to Ordinance by the Minister of Environment of 12 September 2008 on the monitoring of emissions of substances falling under emission allowance trading scheme of the Community which contains a list of materials generally recognized as neutral biomass in terms of CO_2 qualify directly (in group 2) sewage sludge [13].

Possible inclusion of the relevant part of the electricity (and/or heat) produced in the process of conventional fuels and sewage sludge co-combustion must meet certain technological, organizational and formal requirements [14].

For example, the design of individual devices of sewage sludge feeding system should include settlement requirements for the installation and procedures of energy produced from Renewable Energy Sources (RES) [14, 15]. After testing, the energy and emission factors for sewage sludge co-combustion should be developed, so-called credential documentation be submitted to the Energy Regulatory Office as an annex to the proposal for amending the conditions of license for generation of electricity and heat.

Settlement of CO_2 emissions under the assumption of zero emissions from sewage sludge co-combustion does not provide doubt, because it results from their direct mentioning in the definition of the appropriate legal act. Because power engineering limits apply in relation to emissions of carbon dioxide – energetic use of sewage sludge can be a major economic asset.

However, some doubts may appear in the case of settlement requirements for energy produced from RES. Crucial issue in the balancing and certification of energy produced with the use of sewage sludge is reliable to determine the content of their biodegradable fraction.

Developed by the European Committee for Standardization (CEN, French: Comité Européen de Normalisation) test procedures for solid recovered fuels (SRF) provide grounds for the determination of the biodegradable fraction and energy parameters for various fuels produced from waste (including sewage sludge) and containing biodegradable fraction [16]. In the case of sewage sludge, discussion may be initiated on whether the energy resulting from the thermal treatment can be considered 100% renewable or not.

Table 1 presents the biodegradable fraction content for three samples of municipal sewage sludge on the background of determinations of this parameter in other examples of the investigated samples, performed at the Institute for Chemical Processing of Coal, based on the selective dissolution method described in the PN-EN 15440:2011 Solid recovered fuels – methods for determination of biomass content [17].

Table 1

Biodegradable fraction contents of selected samples of sewage sludge and other waste – potential renewable fuels [%][1]

Sludge type	Ash (d.b.), A^d	Biodegradable (d.b.) X_B^d	Biodegradable (dry, a.f.b.) X_B^{daf}	Non-biodegradable (d.b.) X_{NB}^d
Sewage sludge I – 190805	22.2	73.4	94.3	4.4
Sewage sludge II – 190805	34.5	59.7	91.1	5.8
Sewage sludge III – 190805	24.1	70.9	93.4	5.0
Sludge I from mechanical separation of pulp, paper and cardboard – 030310	30.1	66.7	95.4	3.2
Sludge II from mechanical separation of pulp, paper and cardboard – 030311	21.8	74.4	95.1	3.8
Fibre and paper sludge I – 030311	35.7	61.5	95.6	2.8
Fibre and paper sludge II – 030311	30.4	65.7	94.4	3.9

[1]d.b. – dry basis, a.f.b. – ash free basis.

Selective dissolution method is preferred in industrial laboratories because this analysis can be performed in a typical laboratory by expert analysts using standard equipment. The results of determination for a sample can be obtained within a maximum of 5 days (in the determination of mass fraction) or 15 days (for determining the share of biomass energy and share of total carbon) which gives this method a great advantage over the method of determination of the biodegradable fraction using carbon isotope ^{14}C, which requires a far longer time to determination (and is much more expensive).

According to the data presented in Table 1, sewage sludge certainly belong to the group of biodegradable waste. However, content of biodegradable fraction determined using the method of selective dissolution and converted to dry state and ash-free state has a level slightly lower than 100%. This may result from shortcomings in the analytical method used but mainly from the fact that the organic fraction of sewage sludge also consists non-biodegradable organic compounds (e.g. surfactants).

The method of selective dissolution uses decomposition of biomass under the influence of concentrated (78%) sulfuric acid (acidic hydrolysis). Products of hydrolysis are oxidized with hydrogen peroxide (the concentration of 35%) to carbon dioxide and water. The use of sulfuric acid and hydrogen peroxide for the selective dissolution of biomass contained in the solid recovered fuels (SRF) allows one to carry out a similar decomposition of biomass, which takes place in natural processes of biodegradation that is during decomposition under the influence of microorganisms on water, carbon dioxide and simple non-toxic chemicals.

Unreacted part of biomass is sludge containing non-biodegradable fraction and mineral substance whose content is determined by the gravimetric method.

Content of biodegradable fraction in the dry state is calculated from:

$$X_B^d = 100 - X_{NB}^d - A^d \tag{1}$$

where: X_B^d – biodegradable fraction content (dry state), %, X_{NB}^d – non-biodegradable fraction content (dry state), %, A^d – ash content (dry state) in solid recovered fuel (sewage sludge), %.

Sewage sludge is a waste of a very complex composition. Sewage sludge contains significant amounts of organic and fertilizing matter, primarily nitrogen and phosphorus compounds. Additionally, it includes toxic substances – organic compounds such as AOX, PCB, PCDD/PCDF, PAH, heavy metals and pathogens. The main part of the organic fraction of municipal sewage sludge comes from human excrement and is a complex mixture of fats, proteins, carbohydrates, lignin, cellulose, amino acids, humic acids and fatty acids [18]. Much of organic matter is present in the form of live and dead microorganisms (bacteria, viruses, parasites and fungi), which due to their relatively high surface area (0.8–1.7 m^2/g) adsorb hydrophobic organic pollutants. Their content depends on the type of wastewater, method of cleaning and method of sludge processing [18]. The sludge can also contain many organic compounds of synthetic origin. This organic part of sludge should not be treated as a renewable energy carrier.

To be sure regarding the actual content of biodegradable fraction in the sludge, one can perform the verification tests based on the ^{14}C isotope method, described also in the PN-EN 15440:2011 [17]. In the ^{14}C method, there are no confounding factors. However this method is more expensive and more difficult to use in industrial laboratories, due to the sample preparation procedure, equipment used and the analysis time (approximately 9 weeks).

For this reason, the method can be used only in specialized laboratories and not for routine determinations. Therefore, it seems that the method of selective dissolution should be the reference method for the determination of biodegradable fraction of sewage sludge, and based on the results of tests performed (for a specified quantity of sludge) renewable energy produced from sewage sludge should be accounted.

Financial advantages of the production of electricity produced from renewable energy sources are in national conditions high (the obligation to purchase energy from renewable energy sources and a much higher purchase price for energy from conventional sources). Therefore, it seems highly reasonable renewable energy production based on sewage sludge, which can complement a wide range of renewable biomass fuels on the market. Settlement amount of renewable energy from their use should be closely linked with the determination of biodegradable fraction content of sewage sludge based on the methodology of selective dissolution.

4. SUMMARY

Sewage sludge is a fuel with relatively low energetic properties, but due to small variation in their physicochemical properties, it is an interesting source of energy for electricity generators. Energy use of sewage sludge can be an economic asset in balancing carbon dioxide emissions of power plants because sewage sludge is biomass considered as carbon dioxide neutral. The inclusion of energy produced from sewage sludge to renewable energy requires clear and precise rules for determining and recording the amount of energy produced based on the biodegradable fraction of the waste. Sewage sludge is biodegradable waste but also contain non-biodegradable organic fraction.

Renewable energy produced with the use of sewage sludge should be billed only for the biodegradable fraction of processed sludge, which quantity can be unambiguously determined based on the method of selective dissolution, as in the case for solid recovered fuels.

REFERENCES

[1] Resolution No. 217 of the Council of Ministers of 24 December 2010 on the *National Waste Management Plan 2014*, Official Journal of the Republic of Poland, No. 101, item 1183 (in Polish).

[2] European Commission DG Environment-B/2, Disposal and recycling routes for sewage sludge scientific and technical sub-component report; 23/10/2001.

[3] WERTHER J., OGADA T., *Sewage sludge combustion*, Prog. Energ. Combust., 1999, 25, 55.

[4] RICHERS U., SCHEURER W., SEIFERT H., HEIN K.R.G., *Present Status and Perspectives of Co-combustion in German Power Plants*, Forschungszentrum Karlsruhe GmbH, Karlsruche 2002.

[5] WERTHER J., *Potentials of biomass co-combustion in coal fired boilers*, [in:] G. Yue, H. Zhang, Ch. Zhao, Z. Luo (Eds.), Proceedings of the 20th International Conference on Fluidized Bed Combustion, Tsinghua University Press, Beijing and Springer-Verlag, Berlin 2009.

[6] STELMACH S., WASIELEWSKI R., ZUWAŁA J., SOBOLEWSKI A., *Municipal sewage sludge as a renewable fuel – a way to co-firing in power plants*, Czysta Energia, 2006, 11, 28 (in Polish).

[7] WASIELEWSKI R., SOBOLEWSKI A., *Co-combustion of municipal sewage sludge with coal*, Nowa Energia, 2009, 2, 8 (in Polish).

[8] WASIELEWSKI R., STELMACH S., *Co-combustion of sludge in the domestic power industry, opportunities and barriers*, [in:] Proceedings of V National Conference on Drying and Incineration of sewage sludge, ABRYS Sp. z o.o., Poznań, 2011, 87 (in Polish).
[9] Journal of Laws of the Republic of Poland (Dziennik Ustaw), 2002, No. 37, item 339, as amended, (in Polish).
[10] Journal of Laws of the Republic of Poland (Dziennik Ustaw), year 2008, No. 206, item 1291 (in Polish).
[11] Journal of Laws of the Republic of Poland (Dziennik Ustaw), 2011, No. 95, item 558 (in Polish).
[12] Journal of Laws of the Republic of Poland (Dziennik Ustaw), 2008, No. 183, item 1142 (in Polish).
[13] Journal of Laws of the Republic of Poland (Dziennik Ustaw), 2010, No. 34, item 182 (in Polish).
[14] ŚCIĄŻKO M., ZUWAŁA J., SOBOLEWSKI A. (Eds.), *Methodological Guide: Procedures for accounting and billing of energy produced in the co-combustion processes*, Towarzystwo Gospodarcze Polskie Elektrownie, Warszawa 2007 (in Polish).
[15] STELMACH S., WASIELEWSKI R., *Balancing and certification of energy produced from sewage sludge*, [In:] *Proceedings of V National Conference on "Drying and Incineration of sewage sludge",* ABRYS Sp. z o.o., Poznań, 2011, 81 (in Polish).
[16] VAN TUBERGEN J., GLORIUS T., WAEYENBERGH E., *Classification of Solid Recovered Fuels*, ERFO, 2005, http://www.erfo.int, February 2005.
[17] EN 15440:2011/AC:2011 Solid recovered fuels. Methods for the determination of biomass content.
[18] ROGERS H.R., *Sources, behaviour and fate of organic contaminants during sewage treatment and in sewage sludge*, Sci. Total Environ., 1996, 185, 3.