Analysis of the Possibilities for Energy Recovery in WWTP

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Abstract In recent years, there has been increasing talk of improving energy efficiency and the ability to reduce greenhouse gases in wastewater treatment plants. This necessitates exploring the possibilities for reducing energy costs and the possibilities for obtaining energy from wastewater. In the present study, an analysis of the energy consumed at different stages of wastewater treatment in a municipal WWTP in the Republic of Bulgaria is made, and the average monthly consumption of electricity required for the treatment of one cubic meter of wastewater is estimated. Based on the collected and analyzed data, an assessment was made of the possibilities for energy recovery from dry matter from sludge, by combustion and anaerobic digestion. The obtained results allow for the reconstruction of a facility and the use of the hitherto unused energy potential contained in the sludge.

Keywords: anaerobic wastewater treatment, cost analysis, energy efficiency, energy recovery, circular economy.

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1 Introduction

Wastewater treatment plants are facilities designed to meet certain standards regarding the quality of treated water. In recent years, new stricter requirements have been imposed on the quality of discharged water, as well as the mandatory biological treatment of wastewater in agglomerates over 2000 inhabitants for the countries of the European Union and removal of nutrients nitrogen and phosphorus in wastewater treatment from settlements with more 10,000 population equivalents (Council Directive No. 91/271/CEE) implies higher costs in their treatment. One of the main operating costs in the WWTP is the energy consumption both in the wastewater treatment and the need for electricity in the dewatering of sludge. This necessitates the need to assess the energy efficiency of these facilities of national importance and to study the possibilities for reducing the consumed energy, as well as the possibilities for restoring such.

Globally, WWTPs consume between 3-5 % of energy (McCarty et al., 2011), making them one of the largest energy consumers managed by municipalities. Different wastewater treatment technologies have different energy costs. WWTP energy consumption depends on the degree of wastewater pollution, the location of the installation, the equipment, as well as the aeration processes. To estimate the energy consumption in different treatment plants Longo et al. 2016 offer key energy efficiency indicators (KPIs) using data available at each treatment plant. Fraia et al. 2018 define an indicator that connects the energy consumption in a treatment plant with the input quantities of BOD. The study defines different performance classes, linking the indicators of specific energy consumption with the parameters for the efficiency of pollutant removal.

One of the ways to reduce energy consumption is to optimize the work and improve the energy efficiency of production systems, as well as the search for opportunities for energy production. Reducing energy consumption in wastewater treatment processes would improve their energy efficiency and, last but not least, lead to a reduction in carbon emissions. The optimization of energy costs could be considered in two directions:

- replacement of the available equipment with more modern one, whose energy consumption should be minimal;

– the possibilities to recover energy from waste products obtained as a result of wastewater treatment.

A study of each phase of the technological scheme of a municipal wastewater treatment plant (Panepinto et al. 2016) offers a multi-stage methodology for assessing the energy aspects of wastewater treatment. The energy balance made makes it possible to make some suggestions for optimizing the work processes in the plant. Indicators for the total energy consumption per m3 are calculated in relation to the amount of pollutants removed. Possibilities for reducing energy consumption are also being explored by Chae K. & Kang J. 2013, offering a methodology for assessing energy independence through appropriate renewable energy technologies using different types of photovoltaics.

The aim of the present study is to analyze the electricity consumed at the individual stages of treatment, as well as to analyze the average monthly consumption of electricity required for the treatment of one cubic meter of wastewater. The paper analyzes the possibilities for energy recovery from dry sludge using different technologies.

2 Methodology

The main stages of wastewater treatment are mechanical treatment, biological treatment and the last stage related to sludge treatment. Each of these stages has a different energy consumption, depending on the amount of treated water, the technology used, as well as the degree of pollution. The quality of treated wastewater is characterized by key indicators, such as the amount of removed organic pollutants, removed suspended solids, chemical and biological oxygen demand, as well as the content of nitrogen and phosphorus, all of which must meet certain standards. The availability of these data, as well as the assessment of total electricity consumption, helps to develop energy performance indicators for wastewater treatment (Longo et al. 2016). Data for the calculation of these indicators are available at each treatment plant. They are related to the total electricity consumption in relation to the volume of treated wastewater (KPL_V), the electricity consumption in relation to the population equivalent (KPL_{RE}), as well as the amount of consumed electricity for the removed COD (KPL_{COD}). The most commonly used indicator expresses energy consumption in relation to the amount of treated water.

$$KPL_V = \frac{EE}{V}\left(\frac{kWh}{m^3}\right) \quad (1)$$

$$KPL_{PE} = \frac{EE}{PE}\left(\frac{kWh}{PE\ year}\right) \quad (2)$$

$$KPL_{COD} = \frac{EE}{COD\ removed}\left(\frac{kWh}{kg\ removed\ COD}\right) \quad (3)$$

Based on this scientific development, an assessment was made of the energy efficiency at each stage in the object of study. The obtained results are summarized in fig. 1. Data on energy consumption for a period of one year relative to the volume of treated water are used. The data are based on daily records made in a municipal WWTP designed for 70,000 population equivalents, with average daily capacity of 13,400 m^3. The average amount of energy required for the treatment of one m^3 of wastewater after the calculations is 0.188 kWh/m^3.

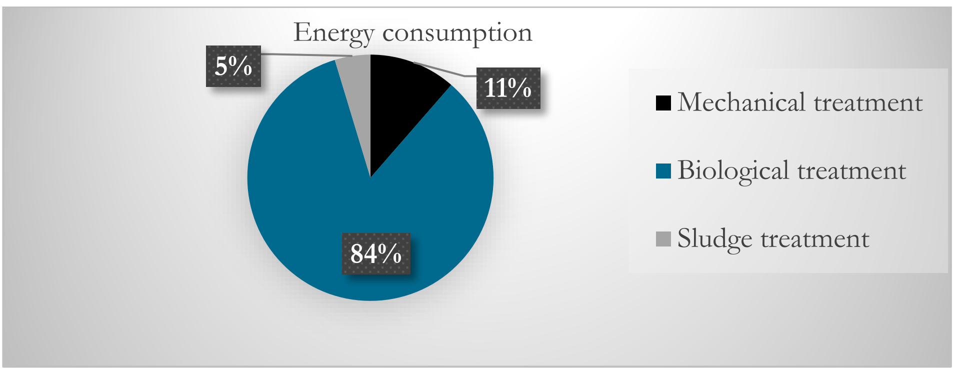

Figure 1: Energy consumption at different stages of treatment

Source: own.

As can be seen from Fig. 1 with the highest energy costs is the stage of biological treatment. At this stage, the wastewater enters bio pools (2 pieces), where denitrification is performed with the help of activated sludge. The activated sludge method used includes oxygen-free nitrogen removal zones. Each bio-pool has three corridors - the first is for pre-denitrification, without aeration, and the other two are aerated, also the free phosphorus is removed in the facility. Passing through the bio-pool, the activated sludge is separated from the treated water into secondary radial precipitators. The wastewater treated in this way is discharged into a water intake, and the activated sludge is returned to the process as recirculated by a pump station for recycling sludge. After aerobic stabilization in the bioreactor and the associated facilities for compaction and dewatering of the sludge in a sludge compactor, the excess activated sludge is removed to drying fields for natural dewatering without the use of special equipment. The reason for the higher energy consumption at this stage is due to the removal of both organic pollutants and the biogenic elements nitrogen and phosphorus.

3 Technologies for energy recovery in WWTP

The analysis of the energy consumption in the WWTP inevitably leads to the study of the possibilities for energy recovery. Over the last decade, the perception of WWTPs has changed and wastewater is considered an energy resource for energy recovery. The energy contained in organic pollutants could be transformed into electrical and thermal, through appropriate technologies. The main source of organic energy in the WWTP is generated as a waste product as a result of wastewater treatment and these are sludge. In many countries, energy recovery technology uses the combustion of sludge as a result of which energy is released. This process is performed at a high temperature to eliminate harmful gas emissions. The amount of energy obtained as a result of combustion depends on the content of organic matter. The moisture content of the sludge as well as the drying methods, in which the treatment costs increase, also have a significant influence. The advantages of this technology is that in addition to energy production, the amount of sludge that must be disposed of is reduced.

Another possibility is the recovery of energy is through the production of biogas. This technology is one of the most common and is suitable for medium and large treatment plants, where anaerobic wastewater treatment is performed using anaerobic microorganisms at temperatures typical of mesophilic microorganisms 33-37 ° C. As a result of their activity, organic substances are decomposed into biogas, containing mainly methane 55-65%, carbon dioxide 30-40%, water and others. The use of the obtained biogas as recovered energy also has some challenges due to the presence of many impurities that must be removed before the biogas can be used.

Another disadvantage of this technology is its not very high energy value (Appels et al., 2008). All this would require additional capital expenditures.

The sludge from the municipal treatment plants is also used for fertilization of agricultural lands, after preliminary analysis, for the presence of harmful substances. Unfortunately, there are many countries that do not use sludge, and dispose of it without further processing.

In Bulgaria, a large part of this waste product is deposited about 90%, the rest is used for land reclamation and biogas production after anaerobic digestion. In order to determine the unused energy potential contained in the sewage sludge in this work is have made an analysis of the possibilities for energy recovery, through the two most common technologies, combustion and energy production from biogas.

3.1 Data

The data for this study summarize the operation of the WWTP and the amount of sludge produced for a period of six years after the reconstruction of the WWTP. The records are summarized for each of the years studied. Table 1 presents the total content of generated sludge in the facility, as well as the amount of dry sludge for the respective year. It is necessary to mention that in the studied WWTP the sludge is deposited in drying fields without additional energy being used for its dehydration, renewable solar energy is used for drying. The dry matter content varies in the range of 24-50% in different years, and the average for the study period is about 36%. This would require minimal amounts of energy in cases where the sludge incineration method is applied. The present study does not consider the amount of energy required to be used in cases of high moisture content to meet the combustion requirement.

Table 1: Quantities of landfilled sludge.

year	dry basis/t	total/t
2014	252.52	979.6
2015	292.56	953
2016	260.46	712.54
2017	219.87	705.48
2018	210.09	388.98
2019	134.39	480.34

4 Results

For the purposes of the study, is used data from Vipin Singh et al. 2020, which explores the energy potential of sludge through combustion and anaerobic digestion. The paper describes that the average potential for energy recovery by incineration of sewage sludge is in the range of about 555-1068 kWh / ton of dry sludge, while the potential for energy generation as a result of biogas production is significantly lower from 315-608 kWh / ton dry sludge. Based on these data, for the purposes of the analysis, the lowest energy values were used for the production of energy from dry matter in both technologies.

After the calculations and the analysis of the data, results are presented for the amount of energy that could be recovered through sludge incineration technology. Fig. 2. The average amount of energy recovered in one year would be ~ 126,715 kWh.

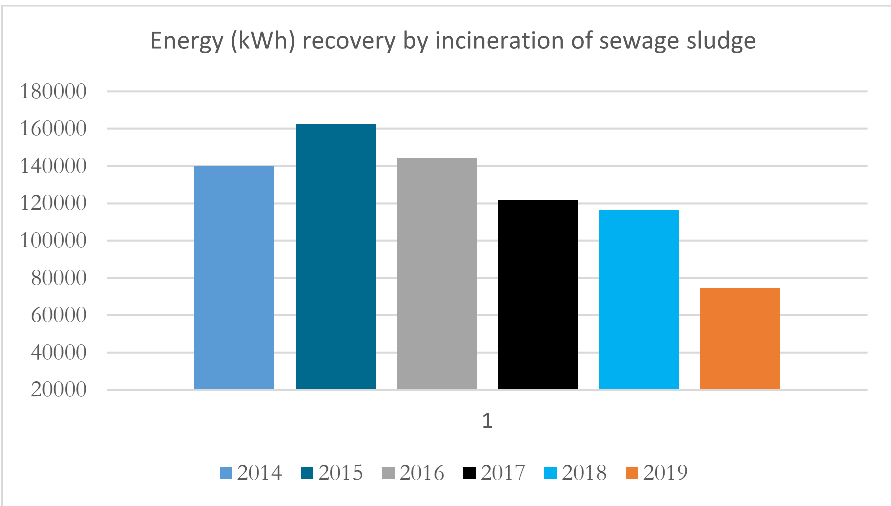

Figure 2: Energy recovery potential of sludge using incineration plants

Source: own.

Or the amount of energy that can be recovered by burning one ton of dry sludge is 92.5 kWh.

Presented results for the amount of energy that could be recovered as a result of biogas production are shown in fig. 3. The average amount of recovered energy for one year in the production of biogas is ~ 71 920 kWh or 52.5 kWh of energy per ton of dry matter.

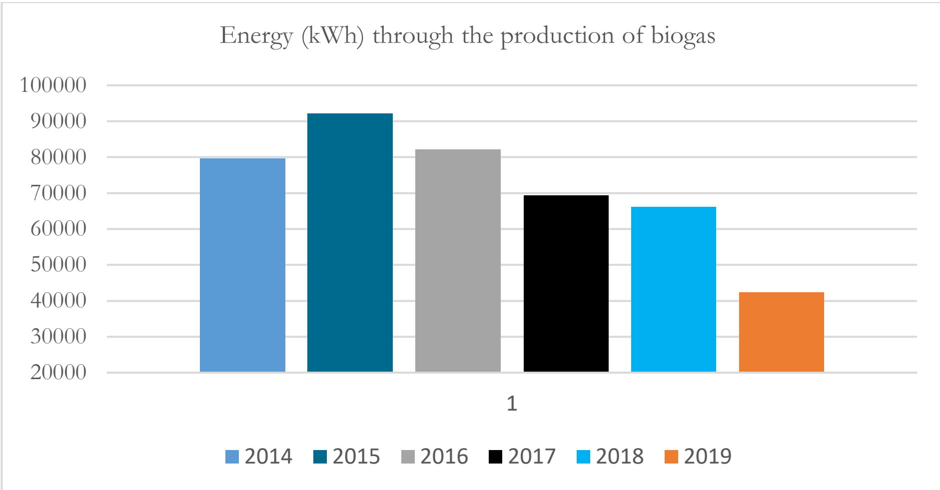

Figure 3: Energy potential of sludge using biogas production
Source: own.

It should be mentioned that these are the minimum amounts of energy that could be recovered. It is also important to say that two methane tanks and a gas holder have been built on the territory of the respective treatment plant, which have not been put into operation at this time. This would reduce the investment costs for reconstruction, and thus the choice of appropriate energy recovery technology.

5 Conclusions

In this study, an analysis was made of the energy consumption as well as the average amount of energy required for the treatment of one m3 of wastewater. Possibilities for energy recovery using sludge as a renewable energy resource were analyzed. The data used for the analysis are based on real records from the WWTP after main reconstruction, in which the removal of nitrogen and phosphorus is carried out. The study provides an opportunity to assess the benefits of modernization and choice of technology for energy recovery from wastewater. The minimum amounts of energy that can be recovered from one ton of dry organic matter by combustion and anaerobic digestion are 92.5 kWh, respectively and 52.5 kWh. The choice of which of these technologies would be more suitable for the respective site is a choice of management decision, which must take into account an analysis of investment costs.

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