ISSN br. 0354-8651

energija

■ ekonomija ■ ekologija

List Saveza energetičara
Broj 3-4 / Godina XVI / Mart 2014.
UDC 620.9

ENERGETIKA 2014

ENERGETIKA 2014.

XXX Međunarodno savetovanje

energija
ekonomija
ekologija

ENERGETIKA 2014.

Ministarstva energetike, razvoja i zaštite životne sredine,
Ministarstva prirodnih resursa, rudarstva i prostornog planiranja,
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ZBORNIK RADOVA

Zlatibor, 25.03. - 28.03.2014

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Energija/Ekonomija/Ekologija

Broj 3-4, mart 2014.

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Kompjuterski prelom EKOMARK
Dragoslav Ješić

Štampa
„Akademska izdanja“, Beograd

Godišnja pretplata
- 8.000,00 dinara
- za inostranstvo 16.000,00 dinara

Tekući račun SE
broj 355-1006850-61

Radovi su recenzirani uz tehničku obradu.

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UDC: 662.767.2 (497.11)

Communal Wastewater Biogas Energy Potential in Kragujevac

ABSTRACT

Biomass energy, which originates from communal wastewater, now receives a specialattention as a very effective and potent source of renewable energy. Communal wastewater is available as a domestic resource and therefore there is no need for its import, as with conventional fuels. Anaerobic digestion of biomass results in biogas (55-75% CH_4). Anaerobic digestion in wastewater treatment plants reduces the amount of final sludge destroying the most of pathogens present in the it. Biogas and its combustion can cover the entire energy requirements of a plant for aeration, digestion, heating, and electricity production and thus they optimaze expenditures of a plant and the impact a plant has on the environment. In this paper, an assessment of the communal wastewater bioenergy potential is conducted using the IPCC 2006 model. The total potential of biogas production from wastewater of urban and rural population on the territory of Kragujevac is estimated at 471 037 Nm3 of biogas.

Key words: biomass, communal water ,anaerigic digestion, biogas.

1. RENEWABLE ENERGY SOURCES

Constant emission of greenhouse gases has led to a significant increase in the concentration of these gases in the atmosphere. In the last two centuries, the concentration of carbon dioxide has increased by 30%, nitrogen oxides by 15%, whereas the concentration of methane in the air is more than doubled, compared with the time before the first industrial revolution. The concentration of methane, in relation to the concentration in 1800, increased by 145% [1]. Increased concentrations of greenhouse gases lead to increased atmospheric heat retention resulting in global warming.

The needs for renewable energy emerged in the past couple of decades after the publication of alarming data on the consequences of the emission of greenhouse gases, produced by the combustion of fossil fuels. This has led to global climate changes, reflected mostly in the average temperature increase and global warming. Another reason for emphasizing the need for research and investment in the field of renewable energy is related to the limited amount of so-called non-renewable energy sources (oil, coal, natural gas, etc.). It is estmated that the present level of these fuels in the world is sufficient to meet the energy demands of mankind for the next fifty years.

Production and usage of energy from renewable sources is still in its infancy, except in some developed countries (Norway, Finland, Germany). Serbia has great potential for energy production from renewable sources, but the potential is largely unexploited. During 2011, 15 million tons of oil equivalent (Mtoe) of primary energy was produced in Serbia, with 53% of energy from coal and lignite, 28% from oil, 12 from natural gas, and with only 7% of energy from renewable sources (*Fig.1*) [2] .

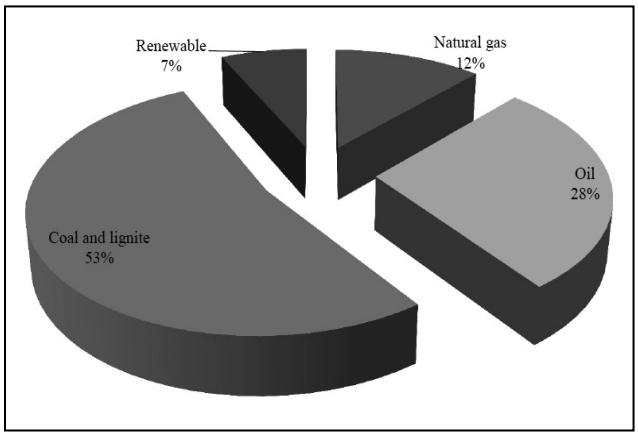

Figure 1. – *Production of primary energy in Serbia*

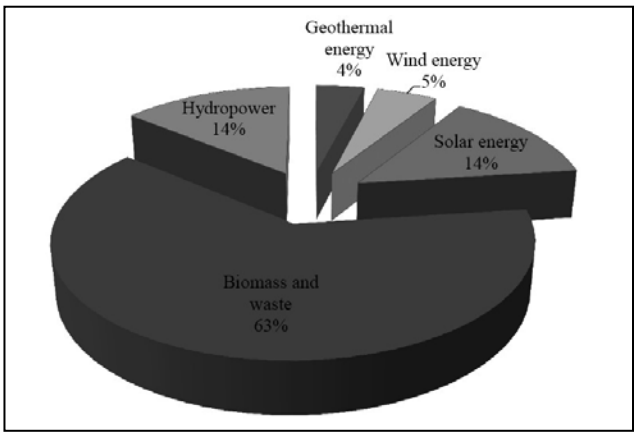

Figure 2. – *Renewable energy sources potential in Serbia*

Figure 2 represents the total estimated renewable energy potential with the estimated shares of each renweable energy source (RES). Technically usable energy potential of these renewable energy sources in the Republic of Serbia is very significant and is estimated at over 4.3 Mtoe per year. It is also estimated that in total energy potential, biomass energy accounts for 2.7 Mtoe, and is followed by hydro energy with 0.6 Mtoe, solar energy with 0.6 Mtoe, and wind energy with 0.2 Mtoe, per year [3].

According to*National action plan for using renewable energy sources until 2020*, it is planned that, based on the obligations of Republic of Serbia arising from Energy Community Treaty, renewable sources energy should participate in bruto final energy consumption in Serbia with 27% in 2020 [4].

1.2 Biomass potential

The use of biomass as an energy source is of interest because biomass is a renewable, potentially sustainable and relatively economical source of energy. The energy generated from biomass will increase renewable sources energy and thus can prolong the existence of conventional sources. [5] The basic concept of biomass as a renewable source of energy reflects in the absorption of solar energy and carbon from the ambient carbon dioxide leading to biomass growth. It is composed of carbon, hydrogen, oxygen, nitrogen, and smaller amounts of sulfur.Biomass combustion produces pollutants including dust and gases, such as sulfur dioxide and nitrogen oxide, which cause acid rain. However, the amount of sulfur dioxide produced during biomass combustion is by 90% lower than during the process of coal combustion.

Biomass can be converted to various forms of bioenergy through various processes. These forms of bioenergy include ethanol, butanol, methane, hydrogen, electricity, biodiesel, and biogas. Another major advantage of using biomass refers to the fact that it is available as a domestic resource and therefore is not subject to changes in price or supply uncertainties as imported conventional fuels. Furthermore, biomass can be employed with the same equipment used to produce electricity, the equipment which exists in plants that burn fossil fuels. Biomass is an important source of energy and the most important fuel worldwide after coal, oil and natural gas [6]. It is the most important renewable energy source in Serbia whose power potential is estimated at 2.7 Mtoe. It is estimated that this power potential could meet 30% of Serbia's energy requirements. Supplies of biomass represent around 60% of the total potential of renewable source energy in Serbia.

Biomass is divided into solid (wood residues), liquid (biodiesel and bioethanol) and gas (biogas). Potential sources of energy are: the remains of the forestry and timber industry, the remains of farming, livestock breeding, fruit and wine growing and primary processing of fruits. The potential of biomass can be utilized to produce electricity and heat. It is also possible to use it for the production of biofuels for transport, and the production of chemicals and bioplastic materials. According to some estimates, only wood remains could provide enough power for 800,000 Serbian households. [3]

All organic substances can be decomplied aerobically and anaerobically with various final products of this process. Decomposition of organic material in the presence of oxygen produces carbon dioxide, ammonia and some other gases. In addition, during aerobic digestion large amounts of heat are released and its final products can be used as fertilizer. In comparison to aerobic digestion, anaerobic digestion produces biogas of smaller heat and final product with greater concentration of nitrogen. Such fertilizer contains nitrogen in a mineralized form (ammonium) which is useful for plants because it easily enriches cultivable land. It is also easier for plants to take mineralized nitrogen than organic.

Biogas is a gas mixture consisting of 35-70% of methane (CH4) and 37-50% of carbon dioxide (CO2), which are known as greenhouse gases. Biogas produced through anaerobic digestion, belongs to a group of combustible gases. Composition and properties of biogas change depending on the type of starting material (biomass) and technological conditions during the digestion process. It can be used in almost every plant which uses natural gas. There are four basic ways to use biogas: in heat and steam production, in electricity and heat production, in automotive fuels production and in chemicals production. At the global level, biogas is mainly used for combined production of electricity and heat energy. Conventional burners can be easily adapted to use biogas by changing the ratio of air and gas.

Finally, it can be freely said that biogas combustion is well established and reliable technology with low requirements in terms of biogas quality [5].

2. PRODUCTION OF BIOGAS FROM WASTEWATER

Waste water can be a source of methane (CH4) when it is treated anaerobically. The amount of methane produced depends primarily on the amount of organic matter in the wastewater, temperature and type of a treatment system. The main factor for determining the methane generation potential is the amount of organic matter in the wastewater. The general parameters used to measure the organic components of wastewater are biological oxygen demand (BOD) and chemical oxygen demand (COD). Under the same conditions, wastewater with higher BOD or COD concentration will generally produce more methane than wastewater with lower COD/BOD concentration.

Methane emissions from wastewater per year can be calculated using the equation (1), which is the method recommended by the International Round Table on Climate Change (IPCC 2006 model) [7].

$$CH_4\text{Emissions}=[\Sigma_{i,j}(U_i \cdot T_{i,j} \cdot EF_j)](TOW-S)-R \qquad (1)$$

where:

CH_4 Emissions, $kgCH_4$/god - stands for methane emission per year,

U_i - for percentage of population in certain regions,

$T_{i,j}$ - for utilization degree of treatment and discharge line or system,

$_i$ - for area: rural, urban, extremely urban,

$_j$ - for each treatment and discharge line or system,

EF_j , $kgCH_4$/kgBOD - for emission factor,

TOW, kgBOD/year - for the total amount of organic material per year,

S, kgBD/year - for organic component removed as sludge,

R, $kgCH_4$/god - for the amount of methane used per year.

Emission factor (*EF*) of treatment and discharge line or system is a function of the maximum potential methane production (B_o) and methane corelation factor (MCF) for each treatment and discharge line or system (Eq. 2). Maximum potential methane production (B_o) is the maximum amount of methane that can be produced with a given amount of organic matter (expressed as BOD or COD) in wastewater. MCF shows the size of the potential methane production (B_o) for each type of a treatment/discharge line and system and it is an indicator of the degree of system's anaerobiosis (*Tab. 1*). The emission factor (EF) is calculated through the following equation:

$$EF_j=B_o \cdot MCF_j \qquad (2)$$

where:

EF_j , $kgCH_4$/kgBOD - stands for emission factor,

$_j$ - every treatment and discharge line or system,

Table 1. – *Standard values of MCF for communal wastewater [7]*

Treatment and discharge line or system type	Comment	MCF	Range
Without treatment			
Discharge into sea, river or lake	Rivers with high organic load can be anaerobic	0,1	0-0,2
Stagnant sewage	Open and hot	0,5	0,4-0,8
Sewageflow (open or closed)	Fast-flowing, clear (slight amount of methane from plant pump)	0	0
With treatment			
Centralizedaerobic plant	Must be well managed. Certain amounts of methane can emission through its sedimentation in the pool	0	0-0,1
	Bad management, over-loaded	0,3	0,2-0,4
Anaerobic sludge digestor	Methane production not consdered	0,8	0,8-1
Anaerobic reactor			
Anaerobicshallow lagoon	Under 2 metres deep, requires expert assessments	0,2	0-0,3
Anaerobna deep lagoon	Above two metres deep	0,8	0,8-1
Septick system	A half of BPK sedimented in anaerobic reservoir	0,5	0,5
Latrine	Dry climate (3-5 users)	0,1	0,05-0,15
	Dry climate (more users)	0,5	0,4-0,6
	Wet climate, greater water consumption	0,7	0,7-1
	Removal of sludge on regular basis	0,1	0,1

B_o , $kgCH_4$/kgBOD - maximum potential methane production,

MCF_j - methane corelation factor.

It is advisedthat recommended values for maximum potential methane production (B_o) should be used in the state, if they exist. If there is no recommended B_o value in the state, a standard B_o value of 0,6 *$kgCH_4$/kgBOD* should be used. For communal wastewater, B_o value presented in HOD can be transformed into a value presented in BOD by multiplying it with2,4 [7].

Total amount of organic substance presents a function of human population and BOD per person (Eq. 3).

$$TOW=P\cdot BOD\cdot 0.001\cdot I\cdot 365 \quad (3)$$

where:

TOW, kgBOD/year - stands for total amount of organic substance per year,

P - population per year (equivalent number of citizens),

BPK - biological consumption of oxygen per citizen on daily basis [g/citizen·day]. Standard value is 60 g/citizen·day

1.1 - conversion from g BOD to kg BOD.

I - corelation factor for discharging industrial BOD into a sewage (value for collected water is 1,25 and for uncollected is 1).

Organic component removed as sludge (S) is proportional to the product of biological oxygen demand (BOD) and specific sludge production (M_{sp}) (Eq. 4). The values of BOD are followed by national statistic agencies and if the value for the certain state is not know, a standard value for a comparable neighbouring state should be taken. Specific sludge production is a parameter that is adopted based on the recommendations and it depends on the value of the organic load in the aeration basin (*Fig. 1*).

$$S=BOD\cdot M_{sp}\cdot 365[kgBOD/year] \quad (4)$$

3. CASE STUDY: BIOGAS PRODUCTION IN KRAGUJEVAC

56% of the Serbian citizenship is connected to sewage system. Around 75% of the population in towns and 9% of the population in rural areas and villages is connected to sewage systems. 151 municipalities have constructed sewage network, while only 12 municipalities have no sewage infrastructure. The highest percentage of the population, connected to the sewage system, is located in a narrow urban areas, while in the suburban areas this percentage is generally very small. 36 minicipalities have a plant for the tretment of wastewater, but there are only 24 whose capacities meet the demands of the population; there are also 5 plants, whose capacity is unsatisfactory, and 7 not-functioning plants [9].

In the city of Kragujevac, 75% of the population is connected to sewerage systems [9]. The municipality has a central plant for wastewater of secondary type in which wastewater is purified in an aeration basin with the activated sludge. Industrial wastewater is discharged into the sewage. 25% of the organic load is removed through primary sedimentation. The rest of the organic load is removed in an aeration basin and secondary fuel filter in order to meet the statutory values of organic load in purified water. The sludge collected is transported to the city dump after its stabilization. This plant has two digestors and it produces around 314t of methane per year. Methane corelation factor of this plant is 0, which means that there is no methane emission from the urban population (MCF = 0). For the rural population, it is assumed that the effulent is disposed of in septic tanks (MCF = 0.5).

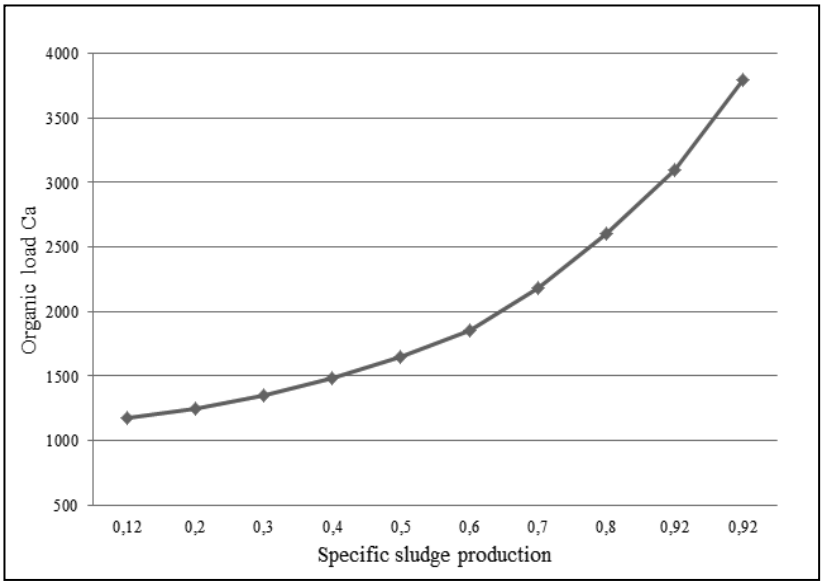

Diagram 1 – *Determination of the specific sludge production [8]*

Methane emissions produced by wastewater from the rural population can be obtained by substituting the appropriate values in the equation (1). Data necessary for the calculation include:

- The percentage of rural population U_i=0.25
- The degree of utilization of the treatment/discharge line or system T=1
- Emission factor $EF_j=B_o\cdot MCF_j=0.6\cdot 0.5=0.3kgCH_4/kgBOD$
- Total amount of organic load per year $TOW=P\cdot U_i\cdot BPK\cdot I\cdot 365=179417\cdot 0.25\cdot 0.06\cdot 365==982308kgBOD/year$

Organic component removed as sludge (S = 0) and the amount of recovered methane per year (R = 0) does not figure in the equation (1) when it

comes to the rural population. Entering the above values in equation (1) gives the value of methane emissions for the rural population (5).

$$CH_4 Emissions = EF_j \cdot TOW = 0.3 \cdot 982308 = 294692.4 kgCH_4/year \quad (5)$$

Methane emissions produced by the relation (1) represent the theoretical value. The actual value is lower for the degree of efficiency of the given system for wastewater treatment, and usually it ranges from 70-90%. If we adopt the value of 80% of separated organic waste, we find that the potential production of methane in the digester is 235 754 kgCH4/year. Given that the percentage of methane in biogas ranges from 55-75%, we find that the possible production of biogas is 362 698.5 kg/year (471 037Nm^3) [10].

Calorific value of biogas depends on the content of methane and for an average content of about 65% of methane it is estimated at 6.4 kWh/Nm3 [11]. Using the obtained biogas for cogeneration plant operation, it is possible to produce 1.2 GWh/year of electricity and 1.6 GWh/year of thermal energy [12].

4. CONCLUSION

Anaerobic decomposition of wastewater contributes significantly to greenhouse gas emissions. Global challenges such as climate change, decrease of oil reserves and rapidly increasing prices, direct discharge of untreated sewage into waterways, and reduction of green areas will encourage the usage and the development of Biogas technology. The use of biogas will reducea negative impact on the environment andhumankind's dependence on fossil fuels. It will also solve the problems arising from energy demands for future generations. The application of anaerobic treatment to municipal wastewater can optimize the overall energy expenditure of the plant. By using the produced biogas to operate the cogeneration plant (which allows a plant for the tretment to operate autonomously). Using the above described methodology, it is estimated that the annual methane emissions from municipal wastewater in Kragujevac is around 295 tons.

5. ACKNOWLEDGMENT

This research was a part of the research project "Research of cogeneration potential of municipal and industrialenergy power plant in Republic of Serbia and opportunities for rehabilitation of existing and construction of new cogeneration plants (III 42013)", which was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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