UDC: 628.4(497.11Leskovac)"2020"
DOI:10.5937/SE2102079N
Research article
www.safety.ni.ac.rs

BRATIMIR NEŠIĆ[1]
JELENA MALENOVIĆ NIKOLIĆ[2]
SRĐAN JOVKOVIĆ[1]

[1]Academy of Technical and Vocational Studies Niš, Department Niš
[2]University of Niš, Faculty of Occupational Safety in Niš

[1]*bratimir@gmail.com*
[2]*jelena.malenovic@znrfak.ni.ac.rs*
[1]*srdjan.jovkovic@akademijanis.edu.rs*

ESTIMATION OF THE ENERGY POTENTIAL FOR THERMAL TREATMENT OF MUNICIPAL SOLID WASTE ON THE TERRITORY OF THE CITY OF LESKOVAC FOR 2020

Abstract: *In addition to material recycling, municipal solid waste (MSW) can be treated with so-called, energy recycling or thermal treatment. The basic conditions that need to be met for this are that MSW can justifiably not be treated with priority material recycling and should have a certain acceptable energy potential for thermal treatment. The paper presents the morphological composition of MSW, generated amount on the territory of the City of Leskovac for 2020, with emphasis on the calculation of the energy potential of MSW, on the basis of which a decision should be made whether material or energy recycling (thermal treatment) will be applied.*

Key words: *energy potential, municipal solid waste, Leskovac*.

INTRODUCTION

Municipal solid waste is waste generated in the household as well as other waste that due to its nature and composition is similar to household waste such as: non-hazardous waste from industrial, commercial institutions (including hospitals) administrative institutions, craft shops, construction waste, green market waste, garden waste, green waste from parks and cemeteries and waste from street cleaning [1].

The option found in waste management operations between recycling and landfilling - energy recycling or thermal treatment for energy recovery in our country even in academic circles, was mentioned sporadically, more as a theoretical possibility. No serious analyses have been made in terms of the "quality" of MSW and especially its energy potential. Based on the morphology of MSW, it can be concluded that Serbia is dominated by biodegradable waste and that its quality in terms of energy recovery is generally poor because it contains moisture even up to 37% [1]. This means that, without prior treatment, not all potentials of thermal treatment of the MSW, can be used. In addition, controlled combustion in plants is also met with great public resistance due to fears of increased pollution. Although the arguments presented as evidence of pollution are generally not scientifically and practically accurate and valid, they still figure among environmental organizations.

Another aggravating circumstance for wider application is the direct or indirect opposition to classical or material recycling. Thermal treatment or controlled combustion for energy recovery, should not and must not be a competition to material recycling because only MSW that cannot be recycled (impure waste) and with satisfactory thermal power or energy potential is thermally treated. However, given the already weaker energy quality of MSW, by taking away fractions for recycling such as plastic, paper or textiles, the already low thermal power or energy potential will be additionally reduced. Of course, this paper will also show whether the qualitatively MSW, generated on the territory of the City of Leskovac in 2020, meets the conditions for thermal treatment, i.e. combustion for energy recovery, i.e. whether its thermal power is at least 6 MJ/kg. The paper is dedicated to the analysis of the energy potential of only MSW, which means that sludge and other liquid municipal waste will not be considered.

MATERIAL AND METHOD

The paper presents the morphological composition of municipal solid waste and the generated amount on the territory of the City of Leskovac for 2020. The emphasis is on the calculation of the energy potential of municipal solid waste, on the basis of which a decision should be made whether to apply material or energy recycling, i.e. thermal treatment of municipal solid waste.

Determining the morphological composition of MSW from the territory of the City of Leskovac

In order to obtain data on the quantities of MSW, it is necessary to implement the prescribed methodology for collecting data on the composition and quantities of MSW on the territory of the local self-government unit [2]. First, the tare mass of all trucks for collecting MSW is measured before going out on the field and collecting and then the same trucks are measured when they perform their regular routes in waste collection and when they are at full capacity (gross mass). All measurements are performed on a truck scale at the entrance to the complex of the regional sanitary landfill

"Željkovac" in Leskovac. Measurements are performed during one week, because for that period, all households on the territory of the City of Leskovac are covered by waste collection service.

To determine the morphological composition of MSW it is necessary that samples of MSW, approximately 500 kg, are delivered to the site for analysis from the following sectors or zones [3]:

- City zone, individual housing,
- City zone: collective housing and commercial zone,
- Rural zones within the city territory.

The analysis should be performed on the same day during the week in which the total amount of MSW is determined, so that the weather conditions are similar and the data are more reliable. The sample from each sector should be selected at random, i.e. by selecting different streets from a particular sector and within them randomly selecting bins/containers to be analysed and which will represent the selected sector as representative as possible.

This part of the methodology can be described as follows:

- Samples from all three zones to be analysed need to weigh about 500 kg.
- Samples from three zones in the city, based on the type of housing.
- The streets that best represent a given zone are selected.
- Within the streets, bins/containers whose contents are unloaded into the truck are randomly selected.
- After the collected mass of the MSW sample, trucks from all three zones are brought to the site for sorting and analysis.
- The total amount of MSW collected in one truck is analysed.
- The sample from all three zones, which is manually sorted, should be separated according to the waste catalogue [4].

As a result of the analysis, the amount of MSW by the above categories in kilograms was obtained, as well as the total amount of the sample, then its volume in cubic meters or litres. The obtained data are analysed and evaluated. However, it should be noted that these results cannot be taken as a definitive indicator of the generated quantities of MSW because there are significant and constant seasonal variations. This only further confirms the fact that the measurements of the generated quantities of MSW are very important for the entire waste management system and that they should be performed constantly throughout the year. The morphological composition of the MSW will be the starting point for further analysis, which is the separation of components that have satisfactory thermal power [5].

The characteristics of MSW, which can potentially become an energy resource [6], depend on several factors: type of development, a saturation of the area with non-residential buildings (including business premises), technical equipment of buildings and their heating. The following elements are equally important for the composition of MSW: the wealth of residents, season, composters for green garbage in the yard and selective collection of MSW that can be recycled by residents [6]. The reason for the special analysis is the decrease or increase in the amount of MSW per capita. The reasons may be an increase or decrease in living standards, but also an increase in public awareness of the importance of reducing MSW generation.

Based on the Annual Report on Waste Management for 2020 [7], the total amount of collected MSW for management (disposal or treatment) is 43.798 tons. The morphological composition of the collected MSW from the territory of the City of Leskovac for 2020, is shown in Table 1.

Energy characteristics of MSW fractions

When considering the possibility of thermal treatment or combustion of MSW in plants and their design, as with any fuel, the following characteristics must be known: chemical composition of MSW as fuel, morphological (physical) composition of MSW as fuel and thermal characteristics of MSW as fuel.

Analysis of chemical composition most often refers to the determination of key elements: carbon, hydrogen, oxygen, nitrogen and sulphur. When the chemical composition of MSW is analysed in terms of its energy potential, it can be said that, like other fuels, it consists of a combustible and a non-combustible part. The combustible part consists of carbon (C), hydrogen (H) and sulphur (S), while the non-combustible part consists of impurities such as oxygen (O), nitrogen (N) and ballast [8]. Ballast consists of mineral impurities (A) and water (W). Mineral substances (impurities) in the process of combustion create ash. In practice, the term ash is often used for pre-combustion conditions. This is the wrong terminology because the composition of mineral substances changes before and after combustion. Mineral impurities and moisture are not elements, but they are conditionally taken in elemental analysis and form the so-called external ballast.

Table 1. *Elemental composition of MSW [9, 10]*

PARAMETER	MSW
Water (%)	15 - 40
Ash (%)	20 - 35
Carbon (%)	18 - 40
Hydrogen (%)	1 - 5
Nitrogen (%)	0,2 – 1,5
Oxygen (%)	15 – 22
Sulphur (%)	0,1 – 0,5
Thermal power (MJ/kg)	7 - 15

The most important component is carbon, whose combustion generates most of the heat (34 MJ/kg), so for the process of energy utilization from MSW, the most important is the presence of fractions with the most carbon content (paper, cardboard, rubber, plastic, wood, etc.). It is completely clear that mineral impurities and moisture are undesirable substances. MSW has an average thermal power, which ranges from 7 to 15 MJ/kg. The heat capacity of MSW in underdeveloped countries is very small and amounts to about 3 MJ/kg while in developed countries it is over 12 MJ/kg. Table 1, shows the elemental composition of MSW [9, 10].

For the thermal treatment of MSW, thermal power is the most important characteristic which is defined as the ratio of the amount of heat released during complete combustion of fuel/MSW and the amount of fuel/MSW from which heat is released [9]:

$$H = \frac{Q}{m} \quad (1)$$

Wherein:
H (MJ / kg) - thermal power;
Q (MJ) - amount of heat released;
m (kg) - mass of fuel / MSW

Moisture reduces the thermal power because part of the heat created by combustion is used for its evaporation. Accordingly, there is a lower thermal power (H_d) and an upper thermal power (H_g). Lower thermal power is the energy that is released after the complete combustion of fuel/MSW whereby water leaves the process in a state of steam (water vapour). Complete combustion implies complete oxidation of carbon to CO_2, hydrogen to H_2O and sulphur to SO_2, without oxidation of nitrogen. The difference between H_g and H_d is the energy required to convert water from the process from a liquid to a vapour state [9]. In most waste incineration systems, water leaves the plant in a state of steam.

MSW, as a potential fuel, is very heterogeneous in its characteristics and differs significantly from conventional fossil fuels. Calculating the heat capacity of MSW is a complex process for which it is very important to determine representative samples for analysis, with possible variations that may affect the final result. Due to the large differences in MSW composition between waste types and variations over time, it is not easy to arrive at a representative sample in order to obtain a reliable estimate of average heat output. The thermal power of MSW would be most accurately determined by testing in an existing thermal treatment plant, by measuring the thermal power for each fraction of MSW using a calorimeter. The process takes place by burning a known mass of MSW, in the presence of oxygen. The amount of energy released during combustion is determined based on the increase in temperature in the calorimeter [9].

Very often, the upper and lower thermal power of fractions are given in the literature [12, 13], where a large difference between the upper and lower thermal power of some fractions can be noticed. Of course, the lower thermal power is relevant for a realistic calculation. All fractions in MSW do not have sufficient thermal power to be considered as a possible energy source. The fractions suitable for controlled combustion in order to obtain energy are given in Table 2.

Table 2. *MSW Fractions Thermal Power [12, 13]*

MSW FRACTIONS WITH SATISFACTORY THERMAL POWER	LOWER THERMAL POWER (MJ/kg)
Paper and cardboard	11,6 - 18,6
Plastics	28 - 37,2
Textile	15 - 18,6
Rubber	21 - 28
Composite materials (Tetra pack)	25,22
Biodegradables	3,5 - 18,6
Fines	2,6

It should be emphasized that the obtained values of thermal powers refer to MSW from bins and containers. By introducing primary selection to obtain recyclable materials, thermal power would have lower values with respect to separated components rich in energy potential.

Estimation of MSW energy potential from the territory of the City of Leskovac for 2020

The process consists of separating fractions that have satisfactory thermal power and neglecting fractions without energy potential. Since the thermal power is known for fuel fractions, then according to the quantitative composition of these fractions in MSW, the thermal power of the fraction or the entire MSW can be obtained by adding the thermal powers of all its fractions. The following fractions participate in the calculation: paper and cardboard, plastic, textiles, rubber, composite materials (tetra pack), biodegradables and fines. Therefore, the mass fraction of all combustible fractions in the sum is less than 100% because the other mass fraction consists of non-combustible fractions.

The morphological composition of the collected MSW from the territory of the City of Leskovac for 2020, is shown in Table 3.

Table 3. *The morphological composition of the collected MSW from the territory of the City of Leskovac for 2020. [7]*

FRACTION	**MASS SHARE (%)**
Paper and cardboard	1,69
Glass	0,63
Biodegradable waste	85,00
PET packaging	0,7
Other plastic packaging waste	0,8
Other plastics	0,84
Metal - ferrous packaging	0,5
Metal - aluminum cans	0,01
Composite materials (Tetra pack)	1,05
Rubber	1,03
Textile	1,01
Fine elements	5,50
Other	1,18
TOTAL:	**100,00**

On the other hand, there is an indirect way to calculate the thermal power by applying appropriate formulas, for which it is necessary to know the content of ash, moisture and combustible substances.

For this, it is necessary to determine the following contents in the MSW, under certain conditions [11]:

- A - ash content (typically 10 - 25% after incineration at 550°C);
- W - moisture content (typically 15 - 35% when dried at 105°C);
- B - share of flammable solid fraction (mass fraction of combustible components, i.e. carbon + volatiles).

By knowing parameters: A, B and W, it can be determined whether MSW can be burned without auxiliary fuel. For this purpose, Tanner's diagram shown in Figure 1 is used [11]. If the data are in the COMBUSTION part of the diagram (humidity W < 50%, ash A < 60%, combustible material B > 25%), this indicates that the combustion process does not require auxiliary fuel i.e. it is considered that the MSW is suitable for conversion into energy through heat treatment.

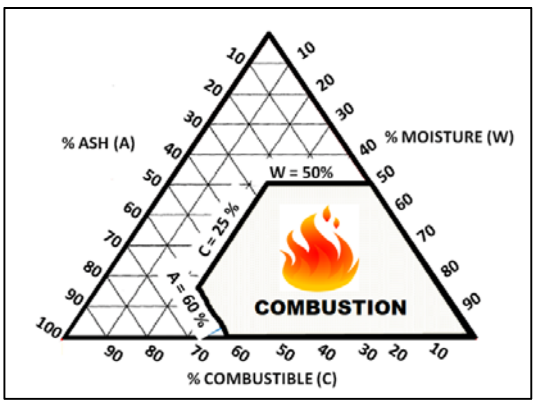

Figure 1. *Tanner's diagram [11]*

Although the values of thermal powers vary considerably from author to author, the average lower thermal powers that appear in the literature for fuel fractions are taken here, so as not to create a false picture of the high energy potential of MSW, especially as the real picture would be reduced for recyclable fractions. The formula for calculating MSW energy potential:

$$E_{Pi} = m_{FPi} \cdot H_{dFi} \qquad (2)$$

Wherein:

E_{Pi} (MJ/kg) – Energy potential of an individual MSW fraction;

m_{Fpi} (-) - Mass share of individual fraction in the total mass of MSW;

H_{dFi} (MJ/kg) - Thermal power of an individual MSW fraction.

Energy potential of MSW collected from the territory of the City of Leskovac for 2020, is shown in Table 4.

Table 4. *Energy potential of* MSW *from the City of Leskovac territory for 2020.*

MSW FUEL FRACTION	Fraction mass share (%)	Fraction mass share (-)	Lower Thermal Power (MJ/kg)	Single Fraction Energy Potential (MJ/kg)
Paper and cardboard	1,69	0,02	16,3	0,33
Plastics	2,34	0,02	32,6	0,65
Textile	1,01	0,01	16,8	0,17
Rubber	1,03	0,01	24,5	0,25
Composite materials (Tetra pack)	1,05	0,01	25,22	0,25
Biodeg-radables	85,00	0,85	11,05	9,39
Fines	5,50	0,06	2,6	0,14
			TOTAL:	**11,21**

By summing the values of energy potentials of all individual fractions, the total energy potential of MSW from the City of Leskovac territory for 2020, was obtained, which amounts to 11,21 MJ/kg. Considering that the limit of energy potential for thermal treatment using the MSW burning technology for energy recovery is 6 MJ/kg, it is obvious that MSW from the City of Leskovac territory for 2020, in terms of energy potential meets this condition.

ANALYSIS OF RESULTS

Although it is completely clear that this is a calculation method, these values of the thermal power of municipal solid waste represent the starting point for further analysis. If there are other data on MSW, for example, the chemical composition of waste fractions, the values of thermal power can be calculated by other calculation methods and compared. When we talk about approximately exact values, possible systematic errors come primarily from the fact that we started from the morphological composition of MSW by seasons and the calculation data were obtained by calculating the arithmetic mean. Since the amounts of MSW by seasons were not the same, the use of the arithmetic means already makes the first mistake in the calculation.

Another error comes from the difference in the values of thermal power of individual fractions of MSW, which can be found in the literature. In this paper, the average values of the lower thermal power of the fractions are taken, which can be found in the literature. Also, these are literary values that refer to certain fractions of certain humidity and quality, which is often not the case in practice because the thermal power is reduced due to excessive humidity, dirt and the like.

It is known that the thermal power of 6 MJ/kg, is the minimum value with which the thermal treatment of MSW for energy recovery can be planned. Although our reality indicates that there will be no construction of such a plant in the near future, further analysis refers to combustion in furnaces within some production activities, primarily in cement plants.

In addition to energy quality, in order to consider the option of thermal treatment of MSW for energy purposes, the condition of quantity must be met, i.e. there must always be sufficient quantities of MSW for combustion. Given that small amounts of generated MSW in all municipalities in Serbia, except large cities (Belgrade, Nis, Novi Sad, Kragujevac and Pristina), it would mean collecting MSW from several municipalities, which can be a logistical problem, both organizationally and financially.

Considering that MSW recyclable fractions, in well-regulated waste management systems, should be recycled, the question arises as to what will remain for combustion after their separation, i.e. what will be the thermal power value? According to some analysis, that it would be around 3 MJ/kg, which is below any level for a serious analysis of a possible thermal treatment for energy recovery. Also, poor quality in terms of humidity and quantities that vary a lot, would deter interested users of this energy source.

CONCLUSION

It is completely clear that the aim is to use all treatment possibilities in the MSW management, except, of course, landfilling. As an option between recycling and landfilling, MSW thermal treatment for energy recovery is somehow shy away. It seems that almost all countries see this option as a "necessary evil", i.e. they apply it when all other options dry up. Even the data on the quantities of MSW that are treated in this way support this and it seems that there will be no significant changes in the coming years.

When we ask ourselves why this option is so neglected and is avoided at all costs, the first argument is the position of public opinion that thermal treatment plants for MSW, pollute the environment. It even seems that public opinion does not see the position and condition of landfills and how they pollute the environment. When it comes to this argument, it should be emphasized that some problems exist, mostly with the solid content that remains after combustion but not to the extent that is shown. A much bigger problem is the cost of building and maintaining an MSW thermal treatment plant to generate energy. Therefore as an option, the possibilities of MSW thermal treatment are sought in some production activities, e.g. cement plants.

When analysing the literature related to this issue in our country, no concrete data can be found on the quality of our MSW, by related, i.e. close municipalities. The proximity of municipalities is important because of the collection of MSW with minimal logistics costs. The general conclusion is that we have low-quality MSW (apart from Leskovac) in terms of energy power and generally small amounts generated for this purpose.

LITERATURE

[1] B. Nešić, ''Generatori otpada i zagađivači južne i jugoistočne Srbije'', Protecta, Niš, Srbija, 2010.

[2] Pravilnik o metodologiji za prikupljanje podataka o sastavu i količinama komunalnog otpada na teritoriji jedinice lokalne samouprave, Službeni glasnik Republike Srbije 61/2010.

[3] G. Vujić, ''Utvrđivanje sastava otpada i procene količine u cilju definisanja strategije upravljanja sekundarnim sirovinama u sklopu održivog razvoja Republike Srbije'', Fakultet tehničkih nauka, Novi Sad, 2009.

[4] Pravilnik o kategorijama, ispitivanju i klasifikaciji otpada, Službeni glasnik Republike Srbije 56/2010, 93/2019, 39/2021.

[5] S. Stanković, ''*Procena energetskog potencijala čvrstog komunalnog otpada u urbanim područjima Republike Srbije*'', završni master rad, Akademija tehničko-vaspitačkih strukovnih studija, Niš, 2020.

[6] K. Midor, K. Jąderko, ''Analysis of the energy potential of municipal solid waste for the thermal treatment technology development in Poland'', E3S Web of Conferences 22, 2017.

[7] Godišnji izveštaj o upravljanju komunalnim otpadom za 2020. godinu privrednog društva RWW Leskovac DOO, Agencija za zaštitu životne sredine Republike Srbije, Beograd, 2021. Available on: *http://www.sepa.gov.rs*

[8] A.T. Akinshilo, J.O. Olofinkua, O. Olamide, ''Energy potential from municipal solid waste (MSW) for a developing metropolis, International Journal of Engineering, Tome XVI, 2018.

[9] M. Radovanović, ''Goriva'', Mašinski fakultet, Beograd, 1994.

[10] B. Nešić, ''Upravljanje komunalnim otpadom i potencijali za reciklažu južne i jugoistočne Srbije'', Protecta, Niš, Srbija, 2010.

[11] B. Cvetanović, ''Energetski potencijal otpada'' (autorizovana predavanja), Akademija tehničko-vaspitačkih strukovnih studija, Niš, 2018. Available on: https://vtsnis.edu.rs/wp-admin/admin.php?page=fajlovi_predmeta

[12] G. Vujić, ''Upravljanje otpadom u zemljama u razvoju'', Fakultet tehničkih nauka, Novi Sad, 2012.

[13] B. Lokahita, M. Aziz, K. Yoshikawa, F. Takahashi, "Energy and Resource Recovery from Tetra Pak Waste using Hydrothermal Treatment", The Open Science Framework, 2017.

ACKNOWLEDGEMENTS

This paper was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (agr. 451-03-9/2021-14/ 200148).

BIOGRAPHY of the first author

Bratimir Nesic was born in Pristina, Serbia, in 1969. He earned a B.Sc. degree in environmental engineering and an M.Sc. degree in environmental engineering from the University of Nis, Faculty of Occupational Safety where he is a Ph. D. student at the moment. He is a member of the Serbian Chamber of Engineers, Serbian Association of Safety Engineers, Serbian Solid Waste Association (SeSWA) and International Solid Waste Association (ISWA). At the moment, he is working as Recycling Manager in Porr Group – Vienna, Austria, PWW Ltd. - Branch Office, Leskovac, Serbia. He is also working as a Lecturer at the Academy for Technical and Educational Vocational Studies Nis, in Nis, Serbia.

His main areas of research include: waste management, waste to energy, energy from waste, recycling, composting, biomass as a renewable energy resource, project management, etc.

PROCENA ENERGETSKOG POTENCIJALA ZA TERMIČKI TRETMAN KOMUNALNOG ČVRSTOG OTPADA SA TERITORIJE GRADA LESKOVCA ZA 2020. GODINU

Bratimir Nešić, Jelena Malenović Nikolić, Srđan Jovković

Rezime: *Pored reciklaže materijala, komunalni čvrsti otpad (KČO) može se tretirati takozvanom, energetskom reciklažom ili termičkom obradom. Osnovni uslovi koji za to treba da budu ispunjeni su da se KČO opravdano ne može tretirati prioritetnom materijalnom reciklažom i treba da ima određeni prihvatljiv energetski potencijal za termičku obradu. U radu je prikazan morfološki sastav KČO, proizvedene količine na teritoriji grada Leskovca za 2020. godinu, sa akcentom na proračunu energetskog potencijala KČO, na osnovu čega treba doneti odluku da li će se primeniti materijalna ili energetska reciklaža (termička obrada).*

Ključne reči: energetski potencijal, komunalni čvrsti otpad, Leskovac.