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Research Article

SIMULATIONS OF THE INFLUENCE OF CHANGES IN WASTE COMPOSITION ON THEIR ENERGETIC PROPERTIES

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ABSTRACT
The objective to obtain the recommended (at least 50% by weight) level of recycled and reprocessed raw fractions of municipal waste in the perspective of 2020 might in turn contribute to the deterioration of the fuel properties of waste stream that is intended for incineration. In order to avoid oversizing heat recovery plants their construction should be based on well-defined properties of the waste fuel. The author carried out simulation calculations of the impact of changes in the composition of municipal waste on their energetic properties. The calculations of the calorific value of the waste fraction (so called combustible fraction) with the potential to be used as an alternative fuel were done.

Keywords: waste management, municipal waste, recycling, calorific value of waste.

INTRODUCTION

The regulations implemented in the area of municipal waste management are aimed at increasing their economic use, and in the case of disposing waste in a landfill, at minimizing their impact on the environment.

It is a legal requirement that municipalities take action to increase the level of recycling and reprocessing of raw fraction of municipal waste by the end of 2020: paper, plastic, glass and metals by a minimum of 50% by weight [Resolution… Dz. U. 2013]. In fulfilling this obligation a special role is attributed to selective collection of recyclable waste fractions, while mechanical and biological processing plants (MBP) of mixed waste may only be a supplementary solution.

The laws also oblige for use in waste management solutions that reduce to an acceptable minimum fraction of organic biodegradable municipal waste disposed of by landfill. To achieve the quantitative requirements in this area may be helpful in backyard composting method of organic waste and the existing and built installations for composting or fermentation of biodegradable waste installations MBP preparing mixed municipal waste to the processing and biochemical plants thermal treatment of mixed municipal waste.

Designing the installations of thermal treatment of waste, such parameters as the amount and characteristics of waste fuel are taken into account. In particular, the characteristics of waste fuel determine the authothermicity of thermal treatment process of waste and the cost of functioning the installations. Waste fuel properties determine the justifiability of subjecting them to a process of thermal treatment. Reducing the share of plastic and paper waste stream may affect the deterioration of calorific value of waste.

The change of morphological composition of combustible fraction of mixed municipal waste may also affect the calorific value of the alternative fuel produced from waste. For example, a reduction of plastic fraction in the waste stream will contribute to lowering the fuel properties of the waste.

By definition, legal regulations are designed to have a positive impact on the management of waste, however, a legal requirement to obtain the recommended level of recycling and reprocessing of selected waste fractions by 2020, may have an adverse impact on the profitability of some waste treatment processes. This applies in particular to the existing plants and the construction of waste thermal treatment, as complying with the aforementioned legal requirement may worsen fuel properties of the waste stream intended for incineration.

The work contained calculations to illustrate the effect of reducing the share of paper and plastic waste stream on the properties of energy waste intended for incineration. The calculation results indicate that it may be necessary to take action to increase the calorific value of the waste directed to the combustion process. Waste fuel properties can be corrected by adding fuels to them, e.g. fuels formed, but keep in mind the adverse impact of such actions on the financial results of companies waste incineration.

GENERAL ASSUMPTIONS OF WASTE MANAGEMENT IN LUBELSKIE VOIVODESHIP

Currently, the system of municipal waste management in Lubelskie Voivodeship includes selective waste collection, waste treatment in order to prepare them for reuse or safe storage and disposal of unprocessed waste in a landfill. Waste processing is carried out in the so-called segregation installations, so called dry waste fraction in installations for mechanical treatment of mixed waste in composting anaerobic facilities for waste treatment. In some installations, mechanical treatment of mixed municipal waste is focused on the production of alternative fuel with simultaneous production of the organic fraction directed to composting. To increase the level of waste recovery, works aimed at the expansion of existing and construction of new installations for this type of waste are carried out. Moreover, in the municipality of Lublin there are plans to build an incineration plant and the construction of MBP [Szyszkowski et al. 2012], which according to the assumptions, will play an important role, alongside selective collection, in fulfilling the obligation to obtain level of recycling and preparation for reusing paper, cardboard, plastics, glass and metals by at least 50% by weight by the end of 2020. To fulfil this obligation, it is equally necessary to implement efficient sorting installations for separately collected waste fractions to ensure the acquisition of high quality, mainly for recycling and to run the installations which will implement the recycling processes. It is believed that the MBP installations for mixed waste will be of limited importance in achieving the required level of recycling and preparation for reusing such material fractions, such as paper, glass, plastics and metals. The materials separated in the recycling systems are inferior in quality, compared to the collected selectively. Consequently, there can be problems in their disposal or recycling due to higher costs as a result of having to undergo an additional treatment such as cleaning. In turn, MBP plants may be important in the production of alternative fuel from waste, currently used in the cement industry. The technological process of the production of alternative fuels from waste should ensure that you obtain the fuel quality parameters which meet customers' requirements. An important parameter is the calorific value of waste, which should be about 20 MJ/kg for applications in the cement industry.

The increase in the selective collection of paper and plastic factions "at source" will reduce the amount of other types of waste, and this in turn can help to reduce the calorific value of the waste [Skowron 2006]. In order to avoid oversizing heat recovery plants, they should be based on well-defined properties of the waste.

Limiting the share of combustible components, plastics in particular, may reduce the calorific value of the fuel. In this regard, paper and cardboard are less significant, as in comparison to plastics they are less calories and more hygroscopic.

When selecting waste treatment techniques and technologies, in addition to the composition and properties of the waste one should consider, the purpose of the processing, the requirements of entrepreneurs involved in recovering the materials obtained in the treatment processes, the economics of the solutions and legal requirements [Marczak 2013].

Based on the data on the amount of municipal waste in Lubelskie Voivodeship, the calculations of the impact of changes in the composition of waste on their energetic properties was made.

EXPERIMENTAL PART

Characteristics of the material

The estimated weight of waste generated in 2012 in Lubelskie Voivodeship amounted to 546920.7 Mg (Table 1). This value is calculated using the rates of waste generation, amounting to

Table 1. Municipal waste generated in Lubelskie Voivodeship in 2012 (own calculations in the basis of [Szyszkowski et al. 2012])

Waste fraction	Waste generation index [kg/M/year]			Amount of waste [Mg]				
	Cities above 50 000	Cities below 50 000	Rural areas	Cities above 50 000	Cities below 50 000	Rural areas	Total [Mg]	Total [%]
Paper and cardboard	64	32	9	34 374	15 117	10 642	60 133	11
Glass	33	34	18	17 780	15 896	21 128	54 804	10
Metal	9	5	4	4742	2338	5104	12 183	2.2
Plastics	51	37	19	27 432	17 299	21 969	66 699	12.2
Multi-material waste	8	13	8	4403	6234	8726	19 363	3.5
Kitchen and garden waste	95	121	60	51 137	56 416	69 500	177 053	32.4
Mineral waste	10	10	11	5588	4519	13 302	23 409	4.3
Fraction < 10 mm	14	23	31	7281	10 597	35 489	53 368	9.8
Textiles	8	14	4	4064	6390	4546	14 999	2.7
Wood	1	1	1	508	468	1397	2372	0.4
Hazardous waste	3	2	2	1355	1091	1742	4188	0.8
Other categories	11	15	9	5926	7169	10 530	23 625	4.3
Bulky waste	9	9	2	4742	4052	2716	11 509	2.1
Green waste	22	18	3	11 706	8260	3250	23 215	4.2
Total	337	333	181	181 036	155 844	210 040	546 921	100
Number of inhabitants (according to Central Statistical Office - Lublin)	537 200	468 000	1 160 444					

337 kg per capita per year (kg/M/year) for the areas of large cities (more than 50 thousand inhabitants), 333 kg/M/year for small cities (up to 50 thousand residents) and 181 kg/M/year for rural areas. The values of total waste generation and different material fractions were adopted from the document „Plan gospodarki odpadami dla województwa lubelskiego 2017" [Szyszkowski et al. 2012].

The estimated share of paper and cardboard in the stream of the generated waste mass was approx. 11%, while the plastic was approx. 12.2% (Figure 1). Municipal waste collected (including the gathered waste) in Lubelskie Voivodeship in 2012, accounted for approximately 346600 Mg [CSO 2013]. Table 2 shows the data on the amount of municipal waste collected in 2012 [CSO 2013].

Based on the data contained in Tables 1 and 2, the amount of waste taken into account in further analysis was estimated. It was determined by subtracting the weight of separately collected waste from the mass of waste generated in 2012, the quantities of waste analysed are presented in Table 3. For ease of calculations the waste was divided into four groups. Group I includes paper, cardboard, glass, metals, plastics, mineral waste, textiles, wood, multi-material waste, hazardous waste, other waste categories. Group II is kitchen wastes. Group III is a waste of grain size <10 mm,

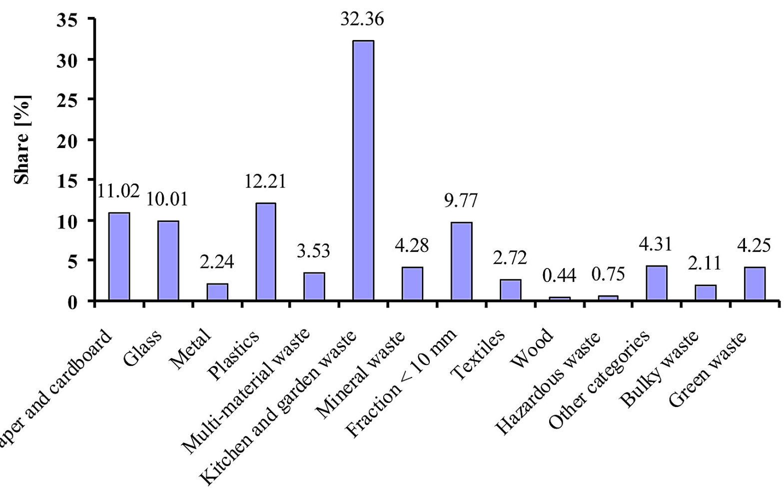

Figure 1. Estimated share of waste fractions in the stream of the generated waste mass in Lubelskie Voivodeship in 2012

Table 2. Amount of waste in Lubelskie Voivodeship in 2012

No	Item	Collected waste [Mg]	Share [%]
1.	Municipal waste (segregated and selectively collected):		
1.1	paper and cardboard	6063.60	1.75
1.2	glass	11693	3.37
1.3	textiles	1947.20	0.56
1.4	hazardous	53.8	0.02
1.5	plastics	5331.50	1.54
1.6	metal	714.90	0.21
1.7	electronic and electric appliances	1395.2	0.40
2.	Waste from parks and gardens:		
2.1	biodegradable	7357.7	2.12
3.	Other municipal waste:		
3.1	mixed	310 545.87	89.60
3.2	bulky waste	1474.5	0.43
4.	Total collected waste	346 577.27	100

while the fourth group is bulky waste and green waste. The masses of individual plastics fractions were determined following Jaglarz [2014] that in the municipal waste stream the share of PE is 27%, PP 6%, and the proportion of PS and PET are 10% and 57%, respectively.

Table 3 shows the moisture content, combustible and non-combustible components in specified fractions. The values of these parameters for waste classified as group IV (including bulky waste and green waste) were not included. This group of waste was not considered in the calculation of the calorific value, since it was assumed that green waste is directed to a biochemical conversion (composting process), while the bulky waste is treated in order to recover recyclable materials which are then passed on to authorized recipients.

Multi-material waste include, among others, packaging and non-packaging composites. For these wastes approximated values of moisture

Table 3. Amounts, composition and characteristics of analysed waste

Group	Waste fraction	Mass waste [Mg]	Share [%]	Moisture* [%]	Combustible components* [%]	Non-combustible components* [%]
I	Paper and cardboard	54 069.88	10.58	25	60	15
	Glass	43 110.54	8.44	0	0	100
	Metal	11 468.19	2.24	0	0	100
	Plastics, in it	61 367.72	12.01			
	PE…………………………..	16 569.29	3.24	0.13**	99.3**	0.57**
	PP…………………………..	3682.06	0.72	0.09**	98.78**	1.13**
	PS…………………………..	6136.77	1.20	0	98.62	1.38
	PET…………….................	34 979.60	6.85	0	96.64	3.36
	Mineral waste	23 409.22	4.58	0	0	100
	Textiles	13 052.06	2.55	0	88.93	11.07
	Wood	2371.86	0.46	20	79.2	0.8
	Multi-material waste	17 967.51	3.52	25	60	15
	Hazardous waste	4133.74	0.81	–	–	–
	Other categories	23 624.86	4.62	–	–	–
II	Kitchen and garden waste	177 053.10	34.66	71.59	21.84	6.57
III	Fraction < 10 mm	53 367.92	10.45	6.47	76.93	16.6
IV	Bulky waste	10 034.97	1.97	–	–	–
	Biodegradable greek waste	15 857.79	3.10	–	–	–
Total group I, II, III		484 996.60	94.93	–	–	–
Total group I, II, III, IV		510 889.36	100	–	–	–

* – According to [Jaglarz 2014].
** – According to [Czop 2013].

Table 4. Moisture content, combustible and non-combustible components for selected groups of waste

Group	Share [%]	Moisture [%]	Combustible components [%]	Non-combustible components [%]
I	52.49	7.27*	45.82*	46.90*
II	36.51	71.59	21.84	6.57
III	11.00	6.47	76.93	16.6
Total group	100	30.66*	40.49*	28.85*

* – Weighted average.

content, combustible and non-combustible components were adopted, as for paper and cardboard. Due to lack of data, Table 3 does not indicate the characteristics of hazardous waste and fractions: other categories of waste.

Table 4 shows the characteristics of the three groups of waste which are included in the calculations of the calorific value. Moisture content of combustible and non-combustible components of the waste in Group I were calculated as weighted averages of the values of these parameters given in Table 3.

Calculations of calorific values of the stream of mixed municipal waste

There is a relationship between calorific value Q_i and the heat of combustion Q_s:

$$Q_i = Q_s - r(W^r + 8.94H^r),\ \ kJ/kg \tag{1}$$

where: r – heat of water evaporation; $r = 2442$ kJ/kg
W^r, H^r – accordingly the content (mass) of moisture and hydrogen in the waste in the operational state, expressed as a decimal fraction (8.94 is the conversion rate of hydrogen to water).

Heat of combustion was determined with Dulong's formula [Chudzinski et al. 1974]:

$$Q_s = 32800\,C^r + 120040\left(H^r - \frac{O^r}{8}\right),\ \ kJ/kg \tag{2}$$

where: C^r, H^r, O^r – respectively the content (mass fraction) of carbon, hydrogen, oxygen in the waste in the operational state, expressed as a decimal fraction.

To convert the contents of individual elements in the waste from the dry to the operating status the following relationship was used:

$$P^r = P^s\left(100 - W^r\right)/100 \tag{3}$$

where: P^r – the content of carbon, hydrogen, oxygen in the waste in the operational state, %
P^s – the content of carbon, hydrogen, oxygen in the waste in the operational state, %
W^r – moisture content in waste, %.

The content of carbon, hydrogen, oxygen in the dry mass of the waste was estimated using the following formula:

$$P^s = \sum_{i=1}^{n} P_i^s u_i \tag{4}$$

where: P_i^s – the content of carbon, hydrogen, oxygen and in different material fractions i,
u_i – shares of individual material fractions in the total mass of waste,
n – the number of material fractions.

Based on the chemical formulas of the fractions, the content of carbon, hydrogen and oxygen were estimated (Table 5). For textiles a simplifying assumption was taken that they are composed of polyester, and the fraction of <10 mm was described in the chemical formula $(C_6H_{10}O_5)_n$. Table 6 shows the shares of carbon, hydrogen and oxygen throughout the waste in the dry state and the operational state calculated according to the equation (3) and (4) taking into account the data given in Table 5. The calculated heat of combustion is:

$$Q_s = 32800 \cdot 0.245 + 120040\left(0.030 - \frac{0.201}{8}\right) =$$
$$= 8621.2\ kJ/kg$$

The calorific value of the waste with calculated moisture 30.66% (Table 4) is:

$$Q_i = 8147.7 - 2442(0.3066 + 8.94 \cdot 0.03) =$$
$$= 7217.5\ kJ/kg$$

The amount of obtainable heat energy E_t from waste can be determined from the relationship:

$$E_t = M\eta u Q_i \tag{5}$$

where: M – waste mass,
η – efficiency of electricity production in cogeneration,
u – share of thermal energy in total energy production in cogeneration.

The projected amount of thermal energy that may be acquired from the waste stream with a mass of 484997 Mg/year (Table 3) and the calorific value of 7217.5 kJ/kg and assuming η = 85% and u = 75% is 2231.5 TJ/year.

Table 5. Content of carbon (C^s), hydrogen (H^s) and oxygen (O^s) in the fractions of waste in the dry state

Waste fraction	Chemical formula	C_i^s	H_i^s	O_i^s
Paper and cardboard	$(C_6H_{10}O_5)_n$	0.444	0.062	0.494
PE	$(C_2H_4)_n$	0.857	0.143	0
PP	$(C_3H_6)_n$	0.857	0.143	0
PS	$(C_8H_8)_n$	0.923	0.077	0
PET	$(C_{10}H_8O_4)_n$	0.625	0.042	0.333
Textiles	$(C_2O_3R)_n$	0.333	0	0.667
Wood	$(C_6H_{10}O_5)_n$	0.444	0.062	0.494
Multi-material waste	$(C_6H_{10}O_5)_n$	0.444	0.062	0.494
Kitchen and garden waste	$(C_6H_{10}O_5)_n$	0.444	0.062	0.494
Fraction < 10 mm	$(C_6H_{10}O_5)_n$	0.444	0.062	0.494

Table 6. The share of carbon, hydrogen and oxygen in the waste

Chemical element	Share	
	dry state	operational state
C	0.381	0.245
H	0.049	0.030
O	0.352	0.201

Table 8. The share of carbon, hydrogen and oxygen in the waste calculations for the second variant

Chemical element	Share	
	dry state	operational state
C	0.376	0.218
H	0.049	0.027
O	0.379	0.204

Simulation calculations of calorific value of waste with consideration to legal requirements

For visualizing the effect of reduced share of the following fractions in waste: paper and cardboard, metal, glass, plastic, on the calorific value, the calculations (variant 2) assuming that 50% of each of these fractions is removed from the waste. Consequently, (compared to the previous calculation) the mass of these fractions in waste destined for processing will be reduced by half. Moisture content of combustible and non-combustible components of waste mass (after removal of the four waste fractions) are summarized in Table 7.

The shares of carbon, hydrogen and oxygen in the waste in the dry state and the actual state (operating) are given in Table 8.

The calorific value of the waste with moisture of 35.49% (Table 7), estimated from equation (1) is: Q_i = 5874.34 kJ/kg. To ensure autothermicity of waste combustion with the above calorific values it will be necessary to improve the energy characteristics of waste. Improved characteristics of waste fuel can be obtained by adding external fuel e.g. alternative fuel. Such an action will increase the operating costs of waste incineration plants. The results for two variants are presented in Table 9.

An alternative method to the thermal process of processing mixed waste is the mechanical-biological treatment (MBP). The specific technical and technological solutions of the process depend on the intended use of waste fractions separated in the process. In further considerations it is assumed that as a result of mechanical processing alternative fuel will be produced, the fractions are inorganic and organic while the organic fraction is intended for composting. The calculations (3rd variant) of the calorific value of waste fraction (i.e. combustible fraction) were made for a potential use as an alternative fuel. In this vari-

Table 7. Characteristics of waste for the second variant of calculations

Group	Share [%]	Moisture [%]	Combustible components [%]	Non-combustible components [%]
I	42.40	6.92*	41.55*	51.52*
II	44.26	71.59	21.84	6.57
III	13.34	6.47	76.93	16.6
Total group	100	35.49*	37.55*	26.97*

* – Weighted average.

Table 9. The results of calculations

Item	2012	Reducing the amount of materials by 50%
Amount of recyclable waste [Mg/year]	484 997	399 988
Paper and cardboard [Mg/year]	54 069.88	27 034.94
Glass [Mg/year]	43 110.54	21 555.27
Metal [Mg/year]	11 468.19	5734.10
Plastics [Mg/year]	61 367.72	30 683.86
Moisture [%]	30.66	35.49
Combustible components [%]	40.49	37.55
Non-combustible components [%]	28.85	26.97
Calorific value [MJ/kg]	7.217	5.874
Heat energy from waste combustion [TJ/year]	2231.5	1497.9

Table 10. Summary of the results of calculations of the calorific value of the combustible fraction of waste

Item		Value
Stream of waste mass to be processed in MBP installation [Mg/year]		399 988
Combustible fraction		
Amount in the stream of waste [Mg/year]		91 110.23
Share in mass of waste to be processed [%]		22.78
Moisture [%]		12.88
Combustible components [%]		77.34
Non-combustible components [%]		9.78
C [%]	Dry state	0.525
	Operational state	0.467
H [%]	Dry state	0.058
	Operational state	0.05
O [%]	Dry state	0.416
	Operational state	0.352
Calorific value [MJ/kg]		14.747

ant, the calculation assumes that the waste from group II and group III (Table 3) are separated in a mechanical process. The combustible fraction will be constituted from mechanically separated waste classified as Group I: paper and cardboard, plastics, textiles, wood, multi-material packaging waste. The combustible mass fraction was determined by subtracting the mass of glass, metal, hazardous waste, mineral waste and fractions waste: other categories of waste from the mass of the I group waste groups in the second variant. The results of calculations are given in Table 10. The estimated calorific value of combustible waste fraction is 14747.74 kJ/kg.

SUMMARY

The amendment to the Polish law in the area of municipal waste management requires increasing the level of recycling and reprocessing waste useable fractions. The fulfilment of legal requirements will affect the properties of mixed waste to be processed.

In the case of Lubelskie Voivodeship segregation of 50% of the waste feedstock, i.e. 17.52% of waste (included in the categories I – III; Table 3) generated in 2012 will reduce the stream of waste for thermal treatment, which should be taken into account in the design of the intended incineration plant.

The decrease of each fraction by 50% of weight will lower the calorific value of the waste from 7.217 MJ/kg to 5.874 MJ/kg. As a consequence, the amount of energy obtainable from the incineration of waste will reduce, which may affect the profitability of the planned project – the construction of a waste incineration plant.

To ensure autothermicity of the incineration process it will probably be necessary to use additional fuel – formed fuel or fossil fuels. Such actions will have an adverse impact on economic profitability of the waste incineration plant. This may affect the price of collecting waste to such installations.

An alternative to incineration of the mixed waste combustion processing is the mechanical-biological treatment. The calculated calorific value of the combustible fraction of the waste obtained after eliminating 50% of fractions is 14.747 MJ/kg. Alternative fuel from the combustible fraction of waste is currently used in the cement industry, and its further use in the energy sector is now debated.

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