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THE EFFECT OF MECHANICAL PRETREATMENT OF MUNICIPAL SOLID WASTE ON ITS POTENTIAL IN GAS PRODUCTION

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Abstract: The impact of mechanical pre-treatment of municipal solid waste (MSW) on its biogas production potential was examined. Mechanical separation allowed the following size-fractions to be obtained: fine fraction – mineral fraction of municipal solid waste (MFMSW) ($\Phi < 20$ mm), middle fraction – organic fraction of municipal solid waste (OFMSW) (20 mm $< \Phi <$ 80 mm), and coarse fraction ($\Phi > 80$ mm). The most suitable fraction for biological treatment was OFMSW, containing about 76 % of high rate biodegradable organic fraction (HRBOF). The rate constant of degradation for organic compounds in OFMSW was 0.23 d^{-1}. It was shown that total gas production (TGP) during 10 years may achieve 550 m^3/Mg OFMSW.
Mechanical pre-treatment may allow an 45 % decrease of the amount of landfilled MSW resulting in a reduction of greenhouse gas emissions of up to 70 m^3/Mg over 10 years of landfilling (in contrast to MSW landfilling – 213 m^3/Mg). The experimental results revealed that gas production potential should be determined on the basis of HRBOF content and measurements of the biogas production.

Keywords: mechanical-biological waste treatment, high rate biodegradable organic fraction, gas production potential, fermentation, municipal waste morphology

INTRODUCTION

The Council Directive "Landfill Directive" (1999/31/EC) binds the members of European Union to decrease the loads of biodegradable municipal wastes dumped at landfills by about 25 % by the year 2006, 50 % by the year 2009 and 65 % by theyear 2016 in relation to loads dumped in the refernece year 1995. This legislative act (1999/31/EC), posed that in recent years interest in mechanical and biological waste pre-treatment (MBP) has increased.
The mechanical and biological pre-treatment of wastes is one of the fastest developing technologies in municipal solids wastes treatment in contrast to waste landfilling and incineration. The main aim of this technology is to separate particular waste groups and biological treatment of organic fractions of municipal solid wastes (OFMSW) with potential for biogas and heat recovery (Soyez, Plickert, 2003). There are two major concepts of mechanical-biological pre-treatment of wastes.
The first concept assumes that at the beginning of waste treatment there is a mechanical processing with material flow separation. The next step is a biological stage with fermentation or composting processes. The second concept entails the opposite: *firstly* the mixed wastes are biologically treated, and *then* stabilized wastes are mechanically treated with the material flow separation (Bolzonella *et al.*, 2006). In the biological stage either aerobic and/or anaerobic processes may be employed. The investment and treatment costs of OFMSW anaerobic digestion are 1.2-1.5-times higher than the

cost of composting. However, with respect to sustainability, anaerobic digestion of OFMSW to biogas is more favourable than composting, since fossil fuels can be substituted and the CO_2 emissions can be reduced (Gallert *et al.*, 2003).

The sources of biodegradable organic fraction in municipal solid waste are kitchen waste, garden waste and sewage sludge (Wang, Banks, 1999, Madokoro *et al.*, 1999, Houbron *et al.*, 1999, Garcia-Heras *et al.*, 1999). In Poland OFMSW comprises ca. 55 % of the wet mass of MSW (Polish Waste Management Strategy, 2006). The quality and quantity of OFMSW depends on types of residential area from which the waste is collected, and the season. It is influenced by the efficiency of secondary materials separation, mechanical and biological processing (Fruteau De Laclos *et al.*, 1997).

In order to effectively separate the resources from MSW the development of technologies of mechanical waste pretreatment is necessary. Up to now drum sieves have been successfully used all over the world. The operation of the drum sieves allows the following waste fractions to be obtained:

- fine fraction – mineral fraction (MFMSW) with particle diameters D < 20 mm,
- middle fraction – organic fraction (OFMSW) with particles diameters 20 mm < D < 80 mm,
- coarse fraction – with particles diameters 100 mm < D < 300 mm.

Successful implementation of mechanical and biological waste treatment needs application of parameters which characterize the biological potentials of separated fractions in an appropriate way. In the case of OFMSW these parameters would be helpful in assessing its potential in biogas production. In the case of MFMSW, coarse fraction (Residues) and raw MSW these parameters may allow the gas emission during landfilling to be predicted. Röhrs *et al.* (2003) showed that the content of total volatile solids alone is not a valuable parameter for the evaluation of waste biodegradability. The morphological characteristics of waste and the investigation of gas production potential with respirometric tests are also necessary. The activities mentioned above may improve the quality of the substrate for biological treatment. They allow effective biological treatment of waste at high gas production potential. Moreover, estimation of the expected biogas yield is possible. After mechanical separation of the biodegradable fraction of MSW, the recyclable materials should be reused. Unfortunately, in many cases, because of the low quality of separated materials like paper, plastic (too wet and too dirty), together with residual mixed MSW they are landfilled. From that reason, estimates of the gas emission rate during landfilling of raw MSW and fractions with low biodegradability are necessary.

The aim of this study was to determine the effect of the mechanical pretreatment of MSW on the gas productivity of OFMSW, and biogas emission during landfilling of MFMSW, Residuals and MSW in the Waste Treatment Plant at Zakurzewo (N. Poland).

MATERIALS AND METHODS

Waste Treatment Plant

Mechanical pretreatment of MSW in the Waste Treatment Plant at Zakurzewo is carried out on a sorting line with the capacity of 60 Mg/d. On the sorting line the following processes take place:

- mechanical separation of MSW (particle diameters criterion),
- transport of MFMSW to the container, and its use at a landfill as intermediate layers,
- OFMSW collection and its biological treatment in energetic piles,
- separation of secondary materials and Residues from the coarse fraction,
- pressing and balling of the secondary materials.
- landfilling of the Residues.

The drum sieve consists of two parts: the first part has holes of diameter 20 mm, while in the second part the holes are 80 mm in diameter. The Fine fraction (D < 20 mm), screened in the first part and described as MFMSW is used at the landfill site. Middle fraction (20 mm < D < 80 mm), screened

in the second part is described as OFMSW and is firstly purified by workers (e.g. to remove batteries, glass, plastics etc.) and subsequently biologically treated under anaerobic conditions in energetic piles (Fig. 1).
Secondary materials are also separated manually by workers from the coarse fraction (D > 80 mm), remaining after screening. Residues remaining after manual separation of coarse fraction are landfilled.

Sampling procedures
The waste samples were collected four times during the autumn period. One day prior to commencing a new campaign, old waste filling the site of waste dumping site and the sorting line were removed and discarded. On the day of the investigation, the weight of the incoming waste was monitored. The mass of separated fractions (MFMSW, OFMSW, Residues) were measured with ±10 kg accuracy. The masses of secondary materials and hazardous waste were measured with ±0.1 kg accuracy. During the investigations, the weights of mechanically treated waste ranged from 8.0 to 28.1 Mg/d and did not exceed 50 % of sorting line capacity. The laboratory samples, about 10 kg of MSW, MFMSW, OFMSW, and Residues were taken from the average 250 kg waste samples. Figure 1 shows the sampling sites.

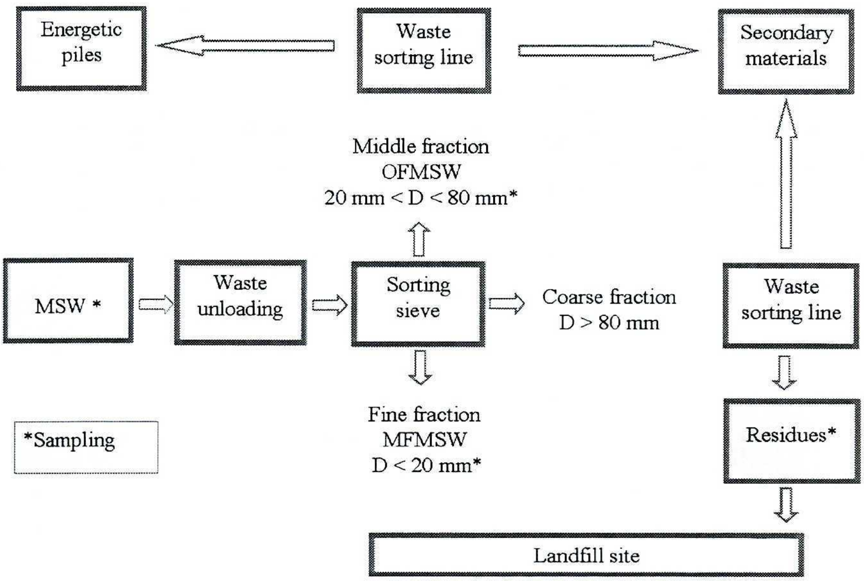

Fig. 1. Scheme of Waste Treatment Plant at Zakurzewo with locations of the sampling locations for MSW, MFMSW, OFMSW, and Residues

Waste analysis
Waste samples were assayed for: morphological characteristics, moisture and total volatile solids content, and gas production potential.

Morphological characteristics
Samples of 2 kg and 5 kg were taken from the average laboratory samples of waste (see Sampling Procedures above). The laboratory waste samples, about 5 kg of (MSW, OFMSW, Residues) were assayed for morphological groups according to Polish standard (PN-93/Z-15006).
The following morphological groups were assayed: paper, kitchen wastes, plastics, textiles, cartons, glass, metals, mineral wastes and hazardous wastes. The weights of the particular morphological groups were measured with ±0.1 g accuracy. It was defined that paper, kitchen wastes, plastics, textiles, cartons are total organic fraction (TO), paper, kitchen wastes and cartons are biodegradable organic fraction (BOF), and kitchen wastes are high rate biodegradable organic fraction (HRBOF).

Moisture and total volatile solids
The percentage moisture content in 2 kg of waste samples was determined after 24 h drying to constant weight at 105°C (PN-93/Z-15008/02). Dry waste samples were ground using a mill (SM-200; Retsch), to a particle size of 4 mm. Total volatile solids [% of total solids (TS)] were measured by ignition at 500°C according to PN-Z-150011-3.

Gas production potential (GP)
Fresh masses of MSW, MFMSW, OFMSW and Residues were homogenized by grinding in a mill (SM-200; (Retsch), to a particle size of 4 mm. The gas production potentials of MSW, MFMSW, OFMSW and Residues were determined according to the methodology proposed by Heerklange, Stegman (2005). An OxiTop system (WTW), was employed in the experiment. The samples, 50 g of waste were incubated in OxiTop vessels for 21 days at 35 °C and at the natural moisture content according to PN-EN ISO 11734:2003. The respirometric measurements were carried out in triplicate. Kinetic parameters of the gas production were evaluated using the following equation:

$$GP = GP_0(1 - e^{(-k \cdot t)}) \quad (1)$$

where: GP – gas production in time t [Ndm^3/kg TVS], GP_0 – maximal gas production [Ndm^3/kg TVS], k – 1st order rate constant of the degradation of organic compounds [d^{-1}].

Simulation of total gas production (TGP)
In order to evaluate total gas production within 10 years of the biological treatment the model proposed by Hoeks (1983) was used. It is assumes that from 1 kg of carbon present in organic matter about 0.8 m^3 of gas, containing 50 % of CH_4 and 50 % of CO_2 (temperature 25 ^{0}C, pressure 1 Bar), may be produced, according to the formula:

$$C_6H_{12}O_6 \rightarrow 2.85CO_2 + 2.85CH_4 + biomass + energy \quad (2)$$

Specific gas production [$m^3 \cdot Mg^{-1} \cdot year^{-1}$] can be calculated using the equation:

$$SGP = 0.8 \cdot k \cdot P_0 \cdot e^{-k \cdot t} \quad (3)$$

where: k – 1st order rate constant for degradation of organic compounds [$year^{-1}$], P_0 – the initial concentration of HRBOF in MSW, OFMSW, Residues and TVS in MFMSW [kg/Mg], t – time [year]. On the basis of SGP values for each year, the cumulative curve of gas production and total gas production (TGP) after 10 years of biodegradation was determined [m^3/Mg].

Statistical procedures:

The analysis of variance between mean values of estimated parameters was carried out using the ANOVA test at the significance level of $p<0.05$. The normality of the distribution was confirmed by Szapiro-Wilk's test, whereas the hypothesis of the homogeneity of variances across the groups was verified on the basis of Levene's test. In the text, the standard deviation is shown after the ± symbol. The kinetic parameters of gas production were determined at a significance level of $p<0.05$. Correlation analyses ($p<0.05$) were performed between the parameters of organic matter content (HRBOF, TVS) and the parameters of gas production (k, GP_0).

RESULTS AND DISCUSSION

Mineral fraction (MFMSW) for D < 20 mm and middle fraction (OFMSW) for the diameter ranging from 20 mm to 80 mm were separated in mechanical pre-treatment using storing line with drum sieve. These MFMSW and OFMSW fractions contributed 25.8 and 38.8 % to the weight of waste mass obtained after size-separation, respectively. Hand separation of the secondary materials from the coarse fraction with D > 80 mm was performed. The effectiveness of the hand sorting line was 7.1 % of total mass of MSW. The mass of waste after size-separation and after the sorting line is called Residues; it contributed 28.3 % of waste weight. Residues were landfilled.

To summarize, the weight of landfilled waste was decreased by 45.9 % of MSW, 7.1 % made up the secondary materials obtained by hand sorting and 38.8 % made up OFMSW that was biologically treated in the energetic piles (Tab. 1). The efficiency of OFMSW separation met the desired requirements of Landfill Directive (1999/31/EC) and mechanical and biological waste treatment technology (MBT) (Fricke *et al.*, 2005).

Table 1. Waste balance in Waste Treatment Plant at Zakurzewo during the experimental period

% MSW			
MFMSW	OFMSW	Coarse fraction	
		Secondary materials	Residues
25.8	38.8	7.1	28.3

The content of secondary materials such as paper, plastics, glass and metals in MSW from the city of Grudziądz and the surrounding rural areas was 15.8, 14.6, 7.9 and 1.7 %, respectively, that contributed about 40 % to MSW (Tab. 2).

Kitchen waste made up 50 % of MSW and this value correlated with the average content of biodegradable waste in municipal waste generated in Poland (Polish Waste Manegement Strategy, 2006).

Mechanical treatment caused significant changes ($p<0.05$) in morphological characteristic of separated fractions in comparison with MSW. Kitchen waste (high rate biodegradable organic fraction – HRBOF) in OFMSW was at the level of 76 %. Moreover, the contribution of secondary materials was paper – 7.9 %, plastics – 3.2 % and glass – 8.5 %. Residues obtained after mechanical pre-treatment and hand sorting, consisted significantly ($p<0.05$) of higher values of resources in comparison to MSW and OFMSW. Residues contained paper, plastics, cartons, metals in the following amounts: 32.8, 26.2, 7.2 and 5.7 %, respectively (Tab. 2).

Mechanical treatment of MSW caused significant changes ($p<0.05$) in the organic matter content of the particular waste fractions. Biodegradable organic fraction (BOF) in MSW made up 66.5 %. After size-separation BOF increased to 84 % in OFMSW. Residues contained about 56 % of BOF, however, paper and carton made up over 70 % of BOF (Tab. 2).

High rate biodegradable organic fraction (HRBOF) is an important parameter describing gas production potential. The content of HRBOF in MSW was about 50 %. After screening, the contribution of HRBOF in OFMSW increased to 76 %. Residues were characterized by low content (16.4 %) of HRBOF (Tab. 3).

Table 2. Morphological groups of each waste fraction [% weight]. After mean value standard deviation is given (symbol ±)

Morphological group of waste	Waste type				ANOVA parameters of differences between waste types ($p<0.05$)	
	MSW	MFMSW	OFMSW	Residues	F	p
Paper	15.8±13.0	-	7.9±4.1	32.8±11.6	6.09	0.0213
Kitchen waste	49.3±11.0	-	75.9±5.6	16.4±12.8	33.67	0.0001
Plastics	14.6±6.2	-	3.2±1.7	26.2±14.4	6.39	0.0187
Textiles	2.0±4.0	-	0±0	0.9±1.7	0.64	0.5511
Cartons	1.4±1.4	-	0.1±0.3	7.2±2.7	18.02	0.0007
Glass	7.9±5.5	-	8.5±3.3	2.6±2.1	2.72	0.1189
Metals	1.7±0.9	-	0.6±0.2	5.7±3.8	5.73	0.0249
Minerale	6.9±5.3	-	3.6±2.9	1.8±3.6	1.58	0.2589
Hazardous	0.5±0.6	-	0.1±0.1	6.5±8.2	2.26	0.1602

Table 3. The parameters of examined waste types. After mean value standard deviation is given (symbol ±)

Waste parameter	Units	Waste type				ANOVA parameters of differences between waste types ($p<0.05$)	
		MSW	MFMSW	OFMSW	Residues	F	p
Moisture	%	39.2±8.0	24.0±6.8	43.1±7.6	34.7±7.2	4.96	0.0182
TVS	% TS	48.8±3.2	19.4±4.4	38.0±10.1	77.2±7.6	48.38	0.0000
TO	%	83.1±9.6	-	87.2±3.4	83.4±8.8	0.34	0.7206
BOF	%	66.5±10.4	-	84.0±4.5	56.3±15.2	6.55	0.0176
HRBOF	%	49.3±11.0	-	75.9±5.6	16.4±12.8	33,67	0.0001
k	d^{-1}	0.078 ±0.021	0.035 ±0.007	0.231 ±0.082	0.072 ±0.015	16.31	0.0002
GP_0	Ndm^3/kg TVS	25.3±10.3	10.1±0.89	40.2±10.9	18.7±3.1	10.90	0.0009

Mechanical pre-treatment of MSW influenced the waste properties responsible for its usefulness to biological treatment. After size-separation a significant decrease of moisture content to 24 % was observed in MFMSW in comparison with MSW (Tab. 3). The moisture contents of MSW, OFMSW and Residues were similar and ranged from 34.7 to 43.1 %.

Currently, OFMSW is biologically treated in energetic piles according to SWECO technology. The moisture content in the energetic pile should be maintained in the range from 55 to 65 % (Agopsowicz *et al.*, 2006). In practice, leachate recirculation compensates the shortage of moisture in OFMSW.

Organic matter content expressed as total volatile solids (TVS) in MSW indicated on different relations than in case of morphological characteristic of waste. The highest value ($p<0.05$) of TVS 77 % TS was in Residues and the lowest in MFMSW – 19.4 % TS.

A relatively low amount of TVS – 38 % TS was observed in OFMSW, is characterized by a high content of high rate biodegradable organic fraction. In summary, the organic matter content, expressed as total volatile solids (TVS), is not a valuable parameter for evaluation of waste biodegradability. TVS involves both easily biodegradable and slowly biodegradable organic matter (Röhrs *et al.*, 2003).

All four separated waste classes: MSW, MFMSW, OFMSW and Residues were taken for gas production potential analyses, and simulations of possible gas emission during 10 years landfillng. MSW and OFMSW are wastes commonly used for effective biogas production at landfills, and bioreactors, respectively. It is necessary to assess the biogas production potential from these waste fractions. Residues should be additionally treated for recyclable material separation and reuse. In many cases, these fraction are just landfilled. Also, MFMSW is landfilled or used at the landfill operation regime (as intermediate layers). It is important to characterize the rate of the biogas emission during landfilling of these waste fractions.

After mechanical pre-treatment, the fractions are characterized by differing values of degradation rate constant (k) of organic compounds. The significant ($p<0.05$) differences in kinetic parameters of gas production of MSW, OFMSW, MFMSW and Residues were determined. The highest rate constant (k) 0.231 d^{-1} was determined in OFMSW. In the case of municipal solids waste and Residues, k values were 0.078 and 0.072 d^{-1}, respectively. MFMSW was characterized by the lowest k value – 0.035 d^{-1} (Tab. 3).

In the study of Veeken, Hamelers (1999) on the influence of temperature on degradation, the decomposition rates of some typical components of kitchen waste were similar to values obtained for OFMSW in our experiments. In case of bread and orange peelings k values at the temperature 30 ^{o}C were 0.198 d^{-1} and 0.264 d^{-1}, respectively.

The maximal gas production (GP_0) from OFMSW was the highest and averaged 40 Ndm^3/kg TVS. Biochemical processes in MSW proceeded with the intensity of 25.3 Ndm^3/ kg TVS. MFMSW and Residues showed low potential for gas production GP_0 10.1 and 18.7 Ndm^3/ kg TVS (Tab. 3). The gas production potential of MSW and separated fractions should be determined on the basis of HRBOF content and kinetic parameters of gas production (k, GP_0). This was confirmed by the high values of correlation coefficients (0.897-0.958) between the above mentioned parameters (Tab. 4). However, the correlation between TVS and HRBOF, k, GP_0 was not significant ($p<0.05$). This confirms that TVS is not a valuable parameter for evaluation of gas production potential of waste.

Table 4. Correlation matrix between the parameters of organic matter content (HRBOF, TVS) and parameters of gas production (k, GP_0); r – correlation coefficient, p – calculated probability

	TVS [% TS]	k [d^{-1}]	GP_0 [Ndm^3/kg TVS]
k [d^{-1}]	r = -0.0441 p = 0.956	-	
GP_0 [Ndm^3/kg TVS]	r = 0.0862 p = 0.914	r = 0.9528 p = 0.047	-
HRBOF [%]	r = 0.1516 p= 0.848	r = 0.8967 p = 0.103	r = 0.9579 p = 0.042

The total gas production yields from MSW and the individual waste fractions within 10 years of biological treatment in energetic piles were determined from the degradation kinetics of organic compounds (Tab. 5).

Table 5. Kinetic parameters of total gas production simulation

Parametr	Unit	Waste type			
		MSW	MFMSW	OFMSW	Residues
k	d^{-1}	0.078	0.035	0.231	0.072
P_o	kg/Mg	493	147	759	164

If municipal solid waste were landfilled during 10 years of landfill operation gas emission (TGP) would reach about 214 m^3/Mg. Landfilling of MFMSW and Residues without separated OFMSW may result in the decrease in gas emission to 35-67 m^3/Mg. Biological treatment of OFMSW in energetic piles allows use of about 85 % gas production potential from MSW for energy production. Simulation of total gas production, as proposed by Hoeks (1983), indicated high TGP from OFMSW – 546.9 m^3/Mg.

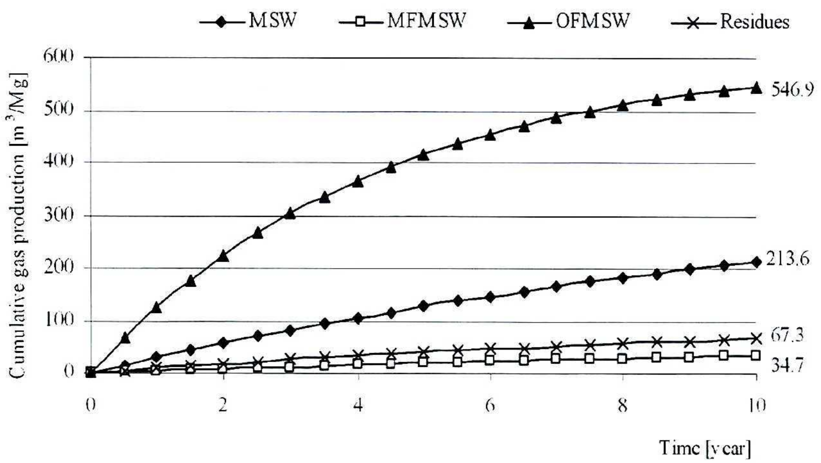

Fig. 2. Cumulative gas production curves from MSW, MFMSW, OFMSW and Residues, on the right side the values of TGP are given

Stegmann and Ehrig (1982) assessed that about 40-45 % of total gas production can be efficiently extracted and reused. The practical biogas production from OFMSW ranges from 218.8 to 246.1 m^3/Mg. Bolzonella *et al.* (2006) obtained similar results in their investigations of biogas production from OFMSW, and fraction separated in mechanical pre-treatment was in the range from 200 to 254 m^3/Mg.

CONCLUSIONS

Mechanical pre-treatment of MSW allows the amount of landfilled waste to be reduced by about 45 %. OFMSW, contributing ca. 38.8 % to MSW, was biologically treated. Secondary materials (7.1 % of MSW) obtained by way of the process,were reused.

Mechanical pre-treatment of MSW causes changes in HRBOF content and kinetic parameters of gas production. After size-separation HRBOF in the middle fraction (OFMSW) increased to 76 % in comparison with 50 % of HRBOF in the MSW. Cumulative gas production of OFMSW was 2.5-fold higher than in case of MSW.

MFMSW and Residues should be separated from MSW, in order to achieve the highest gas production from OFMSW, and landfills with low gas emission.

Biological treatment of OFMSW under anaerobic conditions allows gas production at level 550 m^3/Mg to be achieved.

Landfilling of the waste with low gas production potential (MFMSW, Residues) limits greenhouse gases emission by up to 70 m^3/Mg.

The gas production potential of waste (MSW, MFMSW, OFMSW, Residues) should be determined on the basis of morphological characteristics of the particular fraction of waste, especially HRBOF content, and kinetic parameters of gas production (k, GP_0).

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