INFRASTRUKTURA I EKOLOGIA TERENÓW WIEJSKICH
INFRASTRUCTURE AND ECOLOGY OF RURAL AREAS

No IV/3/2017, POLISH ACADEMY OF SCIENCES, Cracow Branch, pp. 1773–1784
Commission of Technical Rural Infrastructure

DOI: http://dx.medra.org/10.14597/infraeco.2017.4.3.133

ANALYSIS OF THE UNDERSIZE FRACTION TEMPERATURE CHANGES DURING THE BIOSTABILIZATION PROCESS

Mateusz Malinowski
University of Agriculture in Krakow

Abstract

Mixed municipal solid waste collected from the area of each Polish district (commune) is transferred to Regional Installations for Municipal Solid Waste Treatment. They comprise one or more of the following facilities: installations for mechanical-biological waste treatment (MBT), installations for thermal treatment of municipal solid waste, green waste composting plants and landfill sites. MBT installations have been currently the dominant technology of mixed municipal solid waste treatment in Poland. In these installations mixed waste is subjected to mechanical processes (including: crushing, separation, screening and classification) resulting in the production of the undersize fraction with usual grain size below 80mm and the oversize fraction with grain size over 80mm. Because of the necessity of stabilization and hygenization of the undersize fraction prior to landfilling, it is subjected to the process of biological treatment, e.g. biostabilization.

The main aim of the research was to analyze the temperature changes during the biostabilization of the undersized fraction in thermally insulated BKB100 laboratory bioreactor. The research covered a 14-day period of the intensive phase. The analyses were performed in 6 replications. 40.1±2.2kg of waste with density of 519.2±27.5kg·m^{-3} and the biodegradable fraction content of 41.9±1.9% was placed in the reactor. The temperature of waste inside the reactor was measured by 9 Pt 1000 temperature sensors. The air for the process was constantly supplied from the outside of the reactor. Flow of the supplied air with temperature of 18.3±3.1°C was

This is an open access article under the Creative Commons BY-NC-ND license
(http://creativecommons.org/licences/by-nc-nd/4.0/)

regulated depending on the average indication of all temperature sensors. Results of the temperature measurements were averaged and showed using Golden Software Surfer 7.

As a result of the conducted research it was found that changes in the temperature inside the bioreactor occurred uniformly throughout its full volume. The time of reaching the temperature of 45°C (the beginning of thermophilic phase) was 25.6±4.0 hours (21 hours at the earliest). During the first period the temperature in the reactor was increasing most intensively in the lower parts of the layer, in the central part of the layer the temperature reached 45° C after 34 hours at the earliest, whereas on average it took 47.7±9.9 hours. The average maximum process temperature was 64.8±3.5°C.

Keywords: municipal solid waste, undersize fraction, biostabilization

INTRODUCTION

The undersize fraction is separated in mechanical-biological treatment installations (MBT). This fraction may have various grain size, which depends on technological needs and machines used in the process (Bilitewski 2011, Dębicka *et al*. 2013). Most frequently, the undersize fraction is characterized by grain size below 80, 100 or 120 mm). The fraction, according to the Waste catalogue is marked with 19 12 12 code – other waste (including mixed substances and objects) from the mechanical waste treatment, other than mentioned in 19 12 11 (Regulation… 2014). A common feature of the undersize fraction is high content of organic and mineral waste, paper, cullet and small plastics. Morphological composition of the undersize fraction depends mainly on two factors:

- the area where the waste was collected – a higher share of the undersize fraction (irrespective of the season of the year) is noted in the waste originating from rural areas,
- the season of the year – the higher share of the undersize fraction is released from municipal waste collected in winter.

Biostabilization is a process of biological waste treatment, conducted under aerobic conditions and like compositing usually covers two stages (Jędrczak 2008): the stage of intensive (thermophilic) treatment (usually realized in bioreactors) and the maturation stage (in prisms). The process results in generating a new waste – stabilizated waste, in Waste catalogue classified as waste code 19 05 99 (Regulation … 2014), which does not meet the requirements for organic fertilizers or cultivation aids; however, following an additional treatment it may be recycled or disposed of by landfilling.

Biostabilization is a process, which consists in aerobic biodegradation of organic matter in the waste by microorganisms. Its course is similar to com-

posting process course and the main aim is stabilization (reduction of organic carbon and organic matter content) and waste hygenization (removal of pathogenic organisms) resulating from maintaining the temperatures over 60°C (Yuan *et al*. 2017). According to Szewczyk (2016), at the initial phase of the process mesophiles cause an increase in temperature to ca. 45°C and then they die or become inactive, thermophiles replace them and continue the process at higher temperatures. When the stock of organic matter is exhausted, thermophiles die and mesophiles again dominate the process. Actinomycetes prevail at the maturation stage ending the stabilization process. The process is conducted in order to limit the deposited waste mass (particularly biodegradable waste) on the landfill and to reduce greenhouse gases emission from landfills (Sugni *et al*. 2006, Baran *et al*. 2016). Biostabilization process was described in the papers by, among others, Adani *et al*. (2002), Adani *et al*. (2004), Sugni *et al*. (2005), Titta *et al*. (2007), Jędrczak and Szpadt (2008), Dziedzic *et al*. (2015) and Yuan *et al*. (2017). The principles of conducting the process were stated in the Regulation (2012) and in BAT documents (2006). In a majority of the papers mentioned above a single-point temperature measurement during the process was applied. There are no works which would discuss exhaustively the profile of temperature changes inside the bioreactor on its different levels during the biostabilization process of the undersize fraction. The subject literature provides results of research on waste composting or biodrying in which a higher number of probes was used; however, their use was connected with measuring the temperature as a function of the distance from the aerating source or from the perforated bioreactor floor (Dębicka and Żygadło 2017, Tom *et al*. 2016a, 2016b, Białowiec and Templin 2010).

The knowledge about changes in the temperature in the bioreactor during the biostabilization process of waste is extremely important for the proper construction of this type of equipment. A suitable construction, e.g. of the bottom or the whole aeration system in a bioreactor, can improve the achieved final parameters of stabilized waste.

AIM, MATERIAL AND METHODS

The investigations aimed at determining the changes in the temperature profile for the biostabilization process of the undersize fraction in the thermal insulated laboratory BKB 100 type bioreactor with the chamber volume of 116 dm^3 and working height of 99 cm. The bioreactor was constructed of double transparent plastic cover (PC) with water in the space between the cylinders constituting the casing. The reactor was additionally insulated from the outside with a mat filled with rockwool. The main purpose of th performed tests was to carry

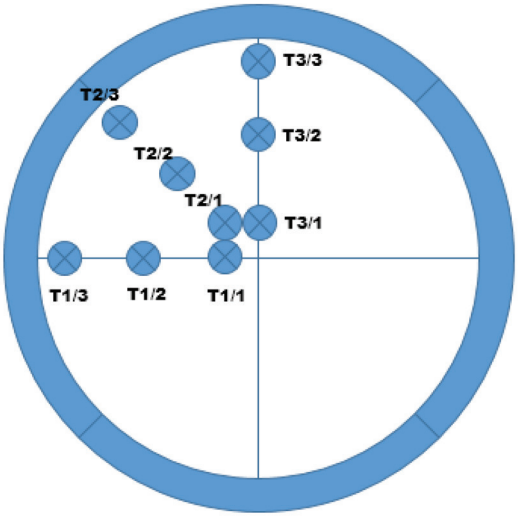
out preliminary analyzes that were to determine the suitability of the device for further testing or to determine the necessity of its modification.

The undersize fraction (Ø < 80 mm) was obtained for the research from MBT installation treating mainly waste from rural areas. The waste for analyses was collected 6 times during the period from mid-April to July, so that it contained the highest possible share of organic matter and biodegradable fraction. Analyses involved 14-day biostabilization (intensive phase) and were conducted in 6 replications. 40.1±2.2 kg of waste was placed in the reactor. The height of waste placed in the reactor was 68.9±3.6 cm. Small amounts of lecheates forming during the process (the container for lecheates was placed under the reactor aerating bottom) were collected every 2 days and returned to the waste in the reactor.

The temperature was measured by means of 9 sensors placed in the bioreactor (Fig.1). The sensors were placed in 3 rows on 3 different heights (10 cm from the bottom, 35 cm from the bottom and 60 cm from the reactor bottom) and on 3 different planes (2 cm from the reactor axis, in the middle of the radius length and 3 cm from the insulating coat). Figure 2 shows the location of the individual sensors. The sensor number consists of two figures, the first of which informs about its length (1 – short, 2 – medium and 3 – long), while the second states its distance from the bioreactor axis. Moreover, the air temperature was measured at the entrance and exit.

Source: Author's own photo

Figure 1. General view of bioreactor



Source: Author's own photo

Figure 2. Location of 9 PT 1000 temperature sensors in bioreactor

The temperatures were recorded by the KSP v1.07 software simultaneously steering the intensity of the bed aerating. The temperature recording from each sensor was conducted in the interval of every 30 seconds. The results of measurements were recorded in Microsoft Excel program. The time of reaching the temperature of 45°C on each of the measuring levels was determined for each measurement. Golden Software Surfer 7 program was used for the visualization of the temperature changes in the bed. The information about averaged temperatures registered by individual sensors every 2 hours in each replication was introduced to this program. Interpolation of the other points made in the program allowed for graphic representation of the temperature changes inside the bed.

The aeration intensity (the air was supplied from the bottom of the reactor through its perforated floor) was regulated according to the Schultz rule, which states that the oxygen demand depends on process temperature as follows (Jędrczak, 2008):

$$W = 0{,}1 \cdot 1{,}067^{t}$$

where:
W – oxygen demand [mg $O_2 \cdot$(g d.m. $\cdot$h)$^{-1}$],
T – temperature in the range of 20-70°C.

The following parameters were determined for the undersize fraction prior to its placement in the bioreactor:

a) density (determined in result of the measurement of the input mass to the reactor and the volume occupied by the waste),
b) morphological composition including determination of the biodegradable waste as the sum of : 100% organics, 100% paper and cardboard, 50% wood, 50% textiles, 40% composite waste and 30% fine fraction, i.e. < 10 mm. Every time the analysis of the percentage of individual waste groups was conducted in 3 replications on the samples weighing 946±153 g,
c) waste moisture (water content in relation to initial mass of a dried sample) by means of PN-EN method 14774:2010 (analyzed at the beginning and end of the 14-day process),
d) loss on ignition and ash content were determined in compliance with PN-EN 14775:2010 (analyzed at the beginning and end of 14-day process).

The samples for laboratory analyses were prepared according to the method recommended by European Committee for Standardization, 2006 Characterization of Waste – Sampling of Waste Materials – Framework for the Preparation and Application of a Sampling Plan (EN 2006, 14899).

RESULTS AND DISCUSSION

The undersize fraction obtained during the period of investigations was characterized by similar shares of individual morphological groups (Tab. 1). Fine fraction (with grain size below 10 mm) prevailed in each measurement. Relatively low share of organic waste was most probably caused by management of such waste at homes in backyard composters or by separate collection of biowaste conducted in the region, whereas a very low content of glass was determined by a large glass mass accumulated separately in rural areas. Average content of biodegradable waste was 41.9%. The lowest share of biodegradable waste – 37.4% was registered for the third replication, whereas the highest for the first replication – 47.3%. Obtained values were approximate to the research results of Wolny-Koładka *et al*. (2016), Baran *et al*. (2016) and Dębicka *et al*. (2017), but were apparently different from the research results of Dziedzic *et al*. (2015), particularly concerning the share of organic fraction, which was much higher in the paper by Dziedzic *et al*. (2015) reaching 40.87%.

Mean density of the undersize fraction was 519.2±27.5 $kg \cdot m^{-3}$, the waste moisture fluctuated on the level of 32.9±2.5%, while loss on ignition, i.e. dry organic matter content was on average 51.5±4.2 (Tab. 2). Declines in moisture and loss on ignition were observed after the process, which evidences that the organic matter contained in the waste was partially mineralized, while a part of water evaporated from the waste. A decrease in loss on ignition by 9.2±2.5% was

a definitely lower than presented in the paper by Dziedzic *et al*. (2015), mainly due to lower content of organic fraction in the treated waste.

Table 1. Morphological composition of the undersize fraction

Waste group	Share
	[%]
Fine fraction < 10mm	25.1 ± 3.6
Organics	17.2 ± 1.8
Paper and cardboard	14.9 ± 3.4
Plastics	15.5 ± 2.3
Metal	1.7 ± 1.0
Glass	6.2 ± 0.9
Textiles and clothing	1.4 ± 0.5
Personal hygiene products	2.1 ± 0.7
Wood	1.1 ± 0.6
Multi-material waste	0.9 ± 0.1
Hazardous waste	0.6 ± 0.2
Inert	2.4 ± 0.7
Other categories	10.9 ± 4.1
Biodegradable waste – total	**41.9±1.9**

Source: Own study

Table 2. Physicochemical characteristics of waste before and after the intensive stabilization process in the reactor

No of samples	Density	Moisture		Loss on ignition	
	$kg \cdot m^{-3}$	before process	after process	before process	after process
		%	%	%	%
1	547.8	33.8	28.4	53.1	40.2
2	538.1	32.4	28.6	49.6	41.1
3	489.0	31.1	28.2	46.1	40.1
4	535.3	36.9	31.8	56.9	48.6
5	523.2	33.3	30.4	48.2	39.7
6	481.7	29.7	26.6	55.3	43.8
Average	**519.2**	**32.9**	**29.0**	**51.5**	**42.3**
SD	**27.5**	**2.5**	**1.8**	**4.2**	**3.4**

Source: Own study

Figure 3 presents a temperature profile of the waste subjected to biostabilization process (replication 1), whereas in Table 3 basic information about the temperatures registered during the process was compiled.

Table 3. Characteristics of the obtained temperature values of treated undersize fraction

No of samples	Reaching the temperature of 45°C		Maximum temperature			Thermophilic phase duration time
	Time	Probe number	Value	Time	Sensor number	
	[h]	%	[°C]	[h]	-	%
1	30.2	T3/1	68.6	83.3	T2/1	158.4
2	22.7	T3/2	63.2	89.4	T2/1	166.9
3	28.1	T3/1	65.2	83.7	T2/1	138.2
4	21.6	T3/1	67.7	82.5	T2/1	209.1
5	29.2	T3/2	58.8	43.3	T2/1	173.9
6	21.8	T3/1	65.3	69.6	T2/1	182.2
Average	**25.6**	**-**	**64.8**	**75.3**		**171.4**
SD	**4.0**	**-**	**3.5**	**17.0**		**23.8**

Source: Own study

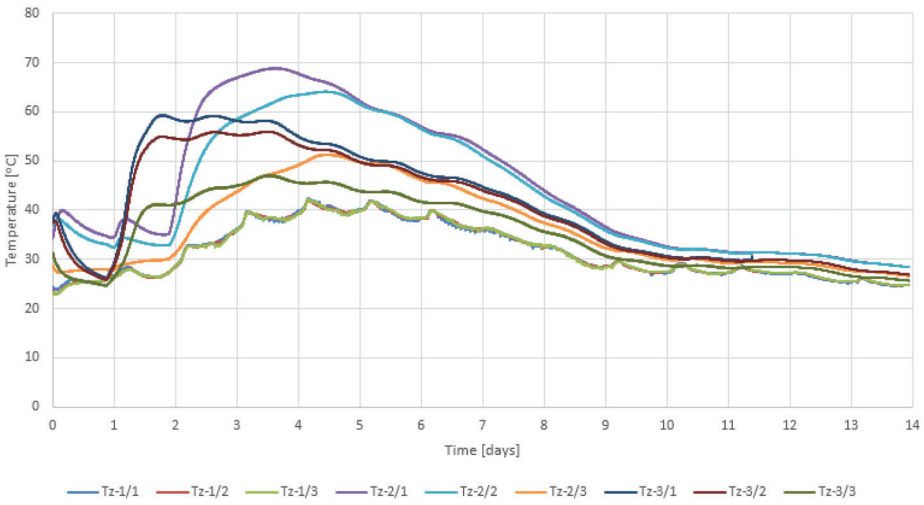
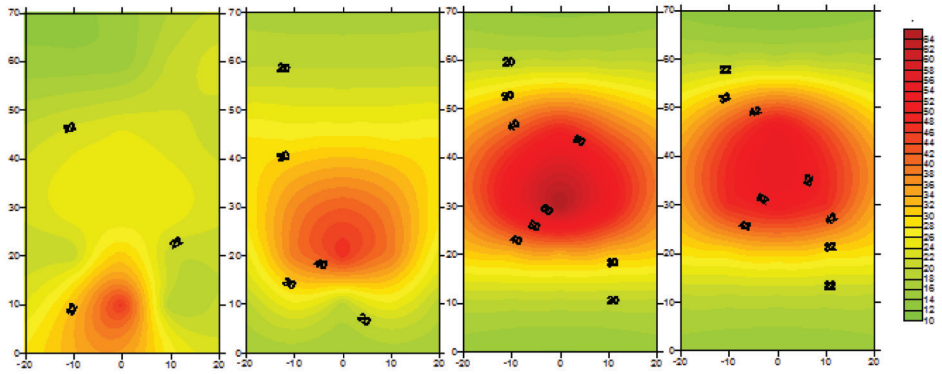


Figure 3. Temperature changes during biostabilization process (replication 1)

For all bioreactors, the thermophilic phase started on the lowest bioreactor level (Tab. 3). In the central part of the bioreactor the waste temperature reached 45°C after 34 hours at the earliest, while on average after 47.7±9.9 hours. The highest maximum temperature was 68.6°C, whereas mean maximum temperature for all replications was 64.8±3.5°C. Maximum temperatures for each replication were registered at the height of 35 cm from the reactor floor after 75.3±17.0 hours. The obtained maximum temperatures, the time when they were reached and the duration time of the intensive phase are similar to the results reported by Tom *et al*. (2016a, 2016b). However, they differ from results presented by Tambore *at al*. (2011), where the duration time of thermophilic phase was only 80 hours and Dziedzic *at al*. (2015), where the time during which the temperature over 45°C persisted in the bioreactor was over 300 hours, but also from Baran *et al*. (2016), where the intensive phase started much later. Thermophilic phase usually starts like in the presented research on the second day of the process.

The analyzed biostabilization process of the undersize fraction is characterized by a gradual increase in the temperature in subsequent waste layers. At increased aeration (e.g. during the waste bio-drying process) this does not happen and the temperature is increasing regularly in each waste layer (Tom *et al*. 2016a, 2016b). Figure 4 presents the course of temperature changes inside the bioreactor conducted using Golden Software Surfer 7 program on the basis of averaged temperature measurements from the subsequent replications of the experiment.



Source: Own elaboration

Figure 4. Spatial profiles of temperature changes during biostabilization in bioreactor (x-axis – height, y-axis – diameter)
(A – after24 hours, B – after 48 hours, C – after 72 hours, D – after 96 hours)

CONCLUSIONS

As a result of conducted research it was found that during the biostabilization of the undersize fraction in laboratory conditions, at controlled air flow and depending on the average temperature inside the reactor:

1. intensive phase of the process starts on average after 25.6±4.0 hours (after 21 hours at the earliest) and lasts about 171.4±23.8 hours (the longest for 209.1 hours). Increase in the temperature in the bioreactor is most intensive until reaching the thermophilic temperature.
2. The intensive phase of the process initially occurs in the lower part of the reactor, then the waste temperature increases in its central part.
3. The maximum temperature (64.8±3.5^{o}C) is reached at the height of 35 cm from the reactor bottom after 75.3±17.0 hours.
4. The temperatures in the upper part of the bioreactor during the process do not exceed 45^{o}C.

In addition, the results of preliminary analyzes presented in the article explicitly recommend the need to change the system of aeration of wastes in this type of bioreactors. It would be advantageous to introduce air not from the bottom of the bioreactor but, for example, through the inner cylinder. Such a solution could enable an even increase of the waste temperature in the bioreactor. This requires further research.

ACKNOWLEDGEMENTS

The publication and research was financed by the Ministry of Science and Higher Education of the Republic of Poland no. BM 4627/2015

REFERENCES

Adani F., Baido D., Calcatera E., Genevini P. (2002). *The influence of biomass temperature on biostabilization-biodrying of municipal solid waste*. Bioresource Technol. 83/3: 173-179. DOI: 10.1016/S0960-8524(01)00231-0.

Adani F., Tambone F., Gotti A. (2004). *Biostabilization of municipal solid waste*. Waste Manage. 24: 775–783. DOI: 10.1016/j.wasman.2004.03.007

Baran D., Famielec S., Koncewicz-Baran M., Malinowski M., Sobol Z. (2016). *The changes in exhaust gas and selected waste properties during biostabilization process*. Proceedings of ECOpole. 10(1): 11-18. DOI: 10.2429/proc.2016.10(1)001

BAT (2006) *Najlepsze dostępne technologie dla przemysłu przetwarzania odpadów*. Sewilla, http://eippcb.jrc.ec.europa.eu/reference/BREF/wt_bref_0806.pdf (data of access: 14.12.2015).

Białowiec A., Templin M. (2010). *Biosuszenie odpadów komunalnych w warunkach zimowych*. Przegląd komunalny. 8: 26-28

Bilitewski B. (2011). *Mechanical Treatment: Unit Processes. Solid Waste Technology& Management*. United Kingdom. A. John Wiley and Sons

Dębicka M., Żygadło M., Latosińska J. (2013). *Investigations of bio-drying process of municipal solid waste*. Ecol. Chem. Eng. A. 20: 1461–1470. DOI: 10.2428/ecea.2013.20(12)132.

Dębicka M., Żygadło M., Latosińska J. (2017). *The effectiveness of biodrying waste treatment in full scale reactor*. Open chemistry. 15: 67-74. DOI 10.1515/chem-2017-0009

Dębicka M., Żygadło M. (2017). *Full-scale biodrying process of municipal solid waste*. E3S Web of Conferences. 17, 00018. DOI: 10.1051/ e3sconf/20171700018

Dziedzic K., Łapczyńska-Kordon B., Malinowski M., Niemiec M.., Sikora J. (2015). *Impact of aerobic biostabilization and biodrying process of municipal solid waste on minimization of waste deposited in landfills.* Chemical and Process Engineering. 36(4): 381-394. DOI: 10.1515/cpe-2015-0027

Jędrczak A. (2008). *Biologiczne przetwarzanie odpadów*. PWN. Warszawa.

PN-EN 14774-3:2010 Solid biofuels – Determination of moisture content – Oven dry method – Part 3: Moisture in general analysis sample.

PN-EN 14775:2010 Solid biofuels – Determination of ash content

Regulation (2014). Rozporządzenie Ministra Środowiska z dnia 9 grudnia 2014 r. w sprawie katalogu odpadów (Dz.U. 2014 poz. 1923).

Regulation (2012). Rozporządzenie MŚ z dnia 11 września 2012 roku w sprawie mechaniczno-biologicznego przetwarzania zamieszanych odpadów komunalnych (Dz. U. 2012. Poz. 1052) – uchylony

Szpadt R., Jędrczak A. (2008). *Wytycznie dotyczące wymagań dla procesów kompostowania. fermentacji i mechaniczno-biologicznego przetwarzania odpadów*. Warszawa. https://www.mos.gov.pl/fileadmin/user_upload/odpady/Wytyczne_dotyczce_wymagan_dla_procesow_kompostowania__fermentacji_i_przetwarzania.pdf. date of access: 04.01.2016.

Sugni M., Calcatera E., Adani F. (2005). *Biostabilization-biodrying of municipal solid waste by inverting air-flow*. Bioresource Technol. 96 (12): 1331-1337. DOI: 10.1016/j.biortech.2004.11.016.

European Committee for Standardization. 2006. Characterization of Waste – Sampling of Waste Materials – Framework for the Preparation and Application of a Sampling Plan. EN 2006. 14899

Szewczyk P. (2016). *Kompostowanie/stabilizacja tlenowa*. Przegląd Komunalny. 4: 45-48

Tambore F., Scaglia B., Scotti S., Adani F. (2011). *Effects of biodrying process on municipal solid waste properties*. Bioresource Technol. 102: 7443–7450. DOI: 10.1016/j.biortech.2011.05.010.

Tom A., Haridas A., Pawels R. (2016a). *Biodrying Process Efficiency: Significance of Reactor Matrix Height*. Procedia Technology. 25: 130-137 DOI: 10.1016/j.protcy.2016.08.240

Tom A., Pawels R., Haridas A. (2016b). *Biodrying process: A sustainable technology for treatment of municipal solid waste with high moisture content*. Waste Manage. 49: 64-71 DOI: 10.1016/j.wasman.2016.01.004

Titta G., Viviani G., Sabella D. (2007). *Biostabilization and biodrying of municipal solid waste*. Eleventh International Waste Management and Landfill Symposium. Cagliari. Sardinia. Italy. 1-5 October 2007. 1085-1086.

Wolny-Koładka K., Malinowski M., Sikora A., Szymonik K., Pelczar G., Wawrzyniak-Turek K. (2016). *Effect of the intensive aerobic biostabilization phase on selected microbiological and physicochemical parameters of wastes*. Infrastructure and Ecology of Rural Areas. IV/1: 1099-1115. DOI: 10.14597/infraeco.2016.4.1.080

Yuan J., Zhang D., Li Y., Chadwick D., Li G., Li Y., Du L. (2017). *Effects of adding bulking agents on biostabilization and drying of municipal solid waste.* Waste Manage. 62: 52-60 DOI: 10.1016/j.wasman.2017.02.027

Eng. Mateusz Malinowski, PhD
University of Agriculture in Krakow
Institute of Agricultural Engineering and Computer Science
Ul. Balicka 116b
30-149 Krakow
Tel: +48 (12) 662 46 60
E-mail: Mateusz.malinowski@urk.edu.pl

Received: 08.01.2016
Accepted: 21.12.2017