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The Bioconversion of Municipal Solid Waste in the Biodrying Reactor

Maria Żygadło* Marlena Dębicka Jolanta Latosińska

Kielce University of Technology, Faculty of Environmental, Geomatic and Energy Engineering, Department of Waste Management, al. Tysiąclecia PP 7, 25-314 Kielce, Poland

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ABSTRACT

The bioconversion process of municipal solid waste was assessed on the basis of the results obtained from the biodrying reactor working at a full industrial scale. The bio- reactor is a part of mechanical-biological installation following mechanical stage. The bio-reactor was equipped with measuring devices allowing the analysis of the parameters like: temperature both inside the waste and also air above the waste and also the humidity of waste during the 14 days of the biodrying process. The kinetics of bioconversion was assessed basing on measured the loss of ignition (LOI) parameter detected during the biodrying process.

The LOI value of the samples varied from 17.03% d.m. to 30.34% d.m. depending on the location inside the reactor. The estimated kinetic rate constant k_T of the bioconversion of biomass in the industrial reactor was $k_T = 0.3141$.

In analyzed case study the calorific value of product leaving the full-scale bio-reactor is too low to use this product as an alternative fuel. As was stated, the reason of this is too low a share of the carbon-rich fraction in the feedstock.

1. Introduction

The landfill directive (EC, 1999) indicates a well established hierarchy in waste management, i.e. prevention, reduction, reuse and recycling, recovery in the form energy and finally landfilling^[1]. In this area incineration of municipal solid waste can be either considered an energy recovery or disposal technology depending on the requirements set by the EU directive 2008/98/EC and according to the calculation of the given formula for R1 included in the aforementioned legislation.

Municipal solid waste (MSW) can be pretreated by bio-

drying prior to incineration to produce a refused derived fuel (RDF) of higher calorific value to raw MSW^[2]. The biodrying process, when the water removal, supported both by the heat produced by the microorganisms in the biodegradation processes and air ventilation, is regarded as a good solution to quickly reduce the water content of the MSW^[3].

The degradation rate of organic waste is determined by biomass characteristics i.e. organic matter content, moisture content, pH and C/N ratio. Also the way of preparation of waste before the processing (composting) play the important role, like particle size of waste allowing to pen-

*Corresponding Author:

Maria Żygadło,

Kielce, University of Technology, Faculty of Environmental, Geomatic and Energy Engineering, Department of Waste Management, al. Tysiąclecia PP 7, 25-314 Kielce, Poland;

Email: zygadlo@tu.kielce.pl

erate the oxygen, free air space, O₂/CO₂ ratio and ammonia concentration^[4]. The degree of waste drying can be varied by the correct regulation of the process parameters in the bio-reactor^[11]. Thus the kinetics of the biodrying process in the bio-reactor for specific biomass depends on the air flow and temperature control along with the natural biodegradable process^[5-6]. The most important are the air-flow rate, temperature and moisture content. A feature of the biodrying together with the moisture lowering is the partial degradation of the organic matter^[7].

2. Materials and Methods

The analysed MBT plant consists of the mechanical stage - the 80 mm sieve - followed by the biological reactor (the biological stage). The biological stage of the industrial installation was represented by a rectangular-shaped, galvanized steel reactor equipped with a module for active aeration connected with a heater (working only in the winter time) and a bio-filter for removing odours. The feedstock directed into the reactor is the fraction 0-80 mm of waste (post sieve) undergoing a drying process for 14 days. The supply fan (air flow 4500 m³ h⁻¹) and the exhaust ventilator (moisture removal 3000 m³ h⁻¹) work continuously.

The investigations of the waste humidity were conducted by the loss of the mass of the dried 1000 g sample at 105° C, according to^[8]. The measurement of the loss on ignition LOI was determined in a muffle furnace at 550 °C for 6 hours using 5 g samples according to the Polish Standard^[9]. The total organic carbon TOC was measured according to the^[10]. The calorific value and heat of combustion were measured in accordance with the Polish Standard and ISO 1928 procedures^[11, 12]. The determination was made on 1 g mass samples placed in a bomb calorimeter in the form of compressed pellet. Ignition of the sample was made using a 0.1 mm diameter kanthal wire embedded into a pellet. The calorific value was calculated by a computer program controlling the operation of the calorimeter. The amount of mercury was determined by PN-EN 12457, chlorine by PN-EN 15408 and lead by ISO 11885^[13-15]. Qualitative tests of waste taken into the MBT installation were made according to Standards^[16] and^[17].

3. Results and Discussion

3.1 Waste Characteristics

The contribution of the biodegradable waste (taking into account the sum of kitchen waste, paper, half of fraction < 10 mm) was about 36%. The share of the typical combustible waste (taking into account the sum of multi-materials, plastic, foils, fabrics) was about 17%. A significant

share in the feedstock, about 32 %, was the contamination by glass and minerals.

Table 1. The average annual morphological composition of the waste directed to the biodrying reactor^[18]

Component	Contribution, σ [*]
Glass	18.02±1.19
Fraction < 10 mm	15.70±0.68
Kitchen waste	16.63±3.69
Mineral fraction	14.02±4.82
Paper	11.08±1.62
Multi-material materials	5.83±0.22
Plastic	5.08±0.19
Ceramic	4.94±0.30
Foils	4.68±0.018
Metals	2.41±0.022
Fabrics	1.61±0.03

Note: σ- standard deviation

The initial moisture content in the waste introduced into the full-scale reactor was 56.5% (Figure 1). The relatively low content of organic matter in the wastes is the result of the implementation of green waste segregation in the given commune. The average initial value of the loss on ignition (LOI) of the feedstock directed into the bio-reactor was about 70%.

3.2 Moisture and Temperature

The variability of the moisture in the examined material in the process of biodrying in a 14-day cycle is presented in Figure 1. Changes in the humidity of the waste were tested in parallel with the changes in temperature (Figure 2).

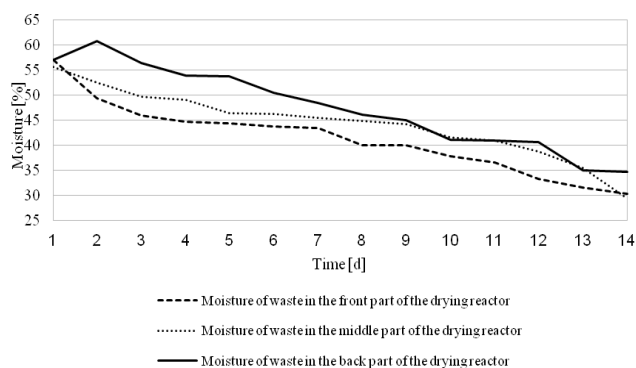


Figure 1. The variability of moisture registered in the different parts of the drying reactor.

Water vaporization is caused by a forced aeration system and the increasing temperature resulting from the activity of microorganisms which consequently leads to a gradually decreasing water content in the raw material. After the 14-day retention time in the bio-reactor, the

moisture content in the waste was reduced from 56.5 to 31.5%, that means by 25 %. This result is similar to that obtained in the study presented in ^[19] (they confirmed about 20 %). The continuous decrease in the total mass of the charge of the reactor is the result of, both the release of the water content, and the partial breakdown of the organic matter ^[20].

Since the temperature inside the waste was the main supporting mechanism of both the water evaporation and the organic matter decaying, the temperature probes was put in different parts of the reactor and in the air above the waste, in the front, middle, back (Figure 2).

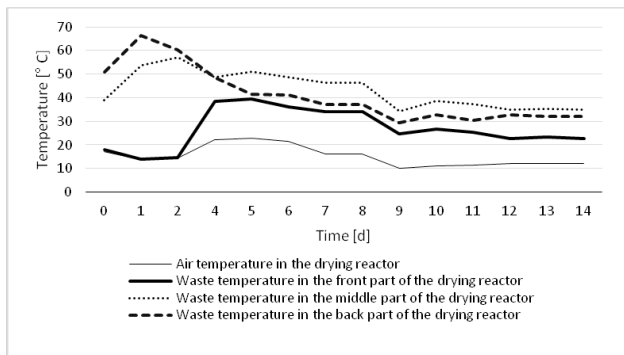


Figure 2. Temperature changes during the 14 days of the biodrying process registered in the different parts of the drying reactor.

The feedstock and inside air temperature was monitored 5 times per day. The highest temperatures were recorded inside the waste in the middle part of the reactor, it was about 70° C and the average values were 43.45° C. The lowest temperatures were registered in the front part of the reactor. The decline in the temperature was similar to the investigations presented in the work ^[21].

The temperature in the middle part of the reactor was optimal for the biodrying process (about 45 °C), which was as confirmed in work of others authors ^[1]. As was observed in our experiment, the degradation process after 7 days slows down due to the decreasing microbial activity that is caused by the lowering water content ^[21].

3.3 Biomass Conversion in the Biodrying Process

The rate of decomposition of the organic matter in the waste depends on many factors ^[22]. These include: the humidity, temperature, C/N ratio and particle size of the waste. The content of the organic matter (OM) in the waste can be estimated approximately basing on the loss on ignition (LOI) (figure 3).

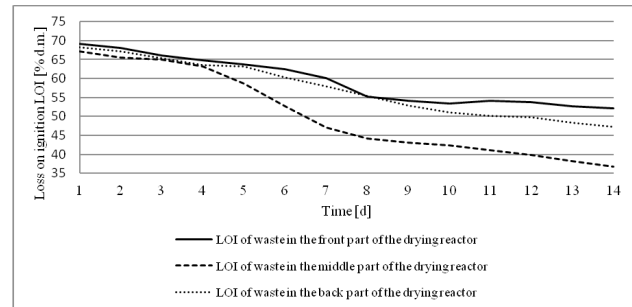


Figure 3. The loss on ignition changes during the 14 days of the biodrying process registered in the different parts of the drying reactor.

It can be seen that in the middle part of the full-scale reactor, the degradation of the organic matter was faster than in the others part. It was connected with the temperature profiles (figure 2) and reflects the microbial activity.

As a result of the biodrying process, about 17% to 34% of the initial dry solid mass in the samples had been transformed and evaporated as CO₂ and H₂O during the 14-day cycle, depending on the place in the bio-reactor. Similar results were obtained by authors in papers ^[21, 23].

The results obtained for the LOI parameter of the waste differed depending on the sampling place in the full-scale bio-reactor. The LOI values decreased by 17.03% d.m. for the samples taken from the front of the reactor; 30.34% d.m. in the middle reactor part and 20.97% d.m. in the back of the reactor. Our results of the biomass losses are comparable to the results given by those presented by work ^[24], where the authors assessed these losses at levels 25-30%.

After the 14 days of retention in the bioreactor, the residual biomass measured by the LOI was in the range of 36- 53% depending on the place of sampling. According to the Regulation of the Polish Minister of Economy of 16 July 2015 on the admission of waste for landfill ^[25] the LOI should be not more than 8%. This result confirms, that after the biodrying process, the waste should be still stabilized before landfilling.

3.4 The Assessment of the Kinetics of the Biomass Conversion

In our research, the loss on ignition (LOI) was taken for the determination of the kinetics of the biomass decomposition during the 14-day biodrying process (figure 3).

The kinetics of the composting process is a reflection of the rate of the decomposition of the organic matter (OM), therefore assuming a first order kinetic to describe it, a simple formula can be used, according to ^[22, 26]:

$$d(OM) / dt = -k_T(OM) \quad (1)$$

Where OM is the mass in kg of the biodegradable volatile solids in a composting process, t is the time in days and k_T is the rate constant of the reaction in d^{-1} .

The estimated kinetic rate constant k_T of the bioconversion organic waste in the biodrying process in the industrial reactor basing on the formula (1) is equal to 0.3141. In Hamoda's work^[22] the value of a constant k_T - taking into account the conditions that were met in our experiment - may change in a wide range: from 0.18 to 0.33. Thus, the results obtained on the basis of the changes in the LOI in our study are within this range determined by Hamoda^[22].

3.5 The Calorific Value of the Product Post Bio-reactor

The calorific value and contamination by Cl, Hg, Pb of the product was determined relative to the requirements for RDF. The comparison of obtained results of biodried waste was made versus the EURITS criteria^[27] and the standard PN -EN 15 359 for RDF^[28]. Results are presented in table 2.

Table 2. The comparison of main parameters of post-bio-reactor product according to criteria for RDF

Parameter	Unit	Biodried fraction	EURITS* criteria	PN -EN 15 359 by grading into classes				
				1	2	3	4	5
Calorific value	MJ/kg	8.48	15.00	≥25	≥20	≥15	≥10	≥3
Cl	%	0,36	0.50	≤0.2	≤0.6	≤1.0	≤1.5	≤3.0
Hg	mg/kg d.m.	1.76	2.00	≤0.02	≤0.03	≤0.08	≤0.15	≤0.50
Pb	mg/kg d.m.	35.3	200.00	Not controlled				

Note: *European Union for Responsible Incineration and Treatment of Special Waste

Data contained in Table 2 prove that after the biodrying process, the product does not meet the requirements specified for RDF, because too low of calorific value. It can be qualified because of low calorific value, up to the fifth class according to PN -EN 15359 standard^[28], what is not satisfactory. The mercury contamination in the light of this norm is too high, although it meets the requirements of the EURITS standard^[27]. Therefore, it is necessary to continue the process of waste bio-drying in order to drain the moisture, which should improve the heat content in the product. It should be noted, that along with the loss of moisture in the biodrying process, there is a bioconversion of organic carbon to carbon dioxide, which adversely affects the calorific value.

4. Conclusions

The efficiency of the biodrying of the waste in the full-scale reactor was analyzed by changes in the temperature, humidity and LOI. During the bioconversion in the biodrying process, about 17% to 34% of the initial dry solid mass in the samples had been transformed and evaporated as CO₂ and H₂O during the 14-day cycle,

The heat generation by the biochemical processes caused a moisture content decline in the waste from 56.5 to 31.5 % which is a 25 % reduction. The most stable temperature conditions were noted for the air temperature in the drying reactor and for the waste located in the central part of the reactor. The middle part of the reactor is the most isolated from the external environment, which allows it to stabilize the process conditions in the shortest time. It can be assumed that the test samples taken from the middle part of the reactor are the most representative for the description of the waste bioconversion kinetics. The average temperature recorded in the middle part of reactor was 43.45° C.

The estimated kinetic rate constant k_T of the waste bioconversion in the industrial reactor was equal to 0.3141.

In analyzed case study the calorific value of product leaving the full-scale bio-reactor is too low to use this product as an alternative fuel. In conclusion, it should be stated that in the context of the suitability of the biodried waste as RDF there is too low a share of the carbon-rich fraction in the feedstock. The justified option for this product is to subject it to further stabilization in order to achieve the requirements for waste sent to landfills, in accordance with the regulation of the Minister^[25].

The presented results were obtained on the basis of the full-scale of the reactor and may be helpful in the design of biodrying reactors for municipal waste in MBT plants.

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