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The Biological Drying of Municipal Waste in an Industrial Reactor—A Case Study

Jolanta Latosińska *, Maria Żygadło and Marlena Dębicka

Faculty of Environmental, Geomatic and Energy Engineering, Kielce University of Technology, Al. Tysiąclecia PP 7, 25-314 Kielce, Poland; zygadlo@tu.kielce.pl (M.Ż.); marlena.debicka@gmail.com (M.D.)
* Correspondence: jlatosin@tu.kielce.pl; Tel.: +48-41-342-4571

Abstract: One of the methods of municipal solid waste (MSW) treatment is biodrying. The literature describes mainly the results obtained in a laboratory- and a pilot-scale reactor. The manuscript presents the results of MSW treatment in a full-scale bio-drying reactor (150 m^3). The reactor is operated in one of the Polish installations specializing in mechanical-biological treatment (MBT). During the 14 day period of biodrying in the reactor, the parameters of MSW such as the moisture, temperature, loss on ignition (LOI), and net heating value (NHV) were examined. The temperature of the air in the reactor was also examined. The research also included changes in the above-mentioned parameters of MSW located in three parts of the reactor: the front, middle, and back. The test results showed that the moisture content of the waste decreased from the initial level of 55% to the level of 30%. This was accompanied by an increase in the NHV from 6.3 MJ kg^{-1} to 9.6 MJ kg^{-1}. At the same time, the LOI decreased from 68% d.m. to 45% d.m. The LOI decrease is not favorable from the point of view of using MSW as refuse-derived fuel (RDF), as was expected in the final usage stage. The results have application value as the plant operator, having at their disposal the controlling of the reactor's ventilation and the temperature inside the reactor, should select the speed of the moisture removal from MSW at such a level as to minimize the LOI decrease.

Keywords: municipal solid waste; mechanical-biological treatment; biodrying; moisture controlling; net heating value controlling; RDF/SRF

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Citation: Latosińska, J.; Żygadło, M.; Dębicka, M. The Biological Drying of Municipal Waste in an Industrial Reactor—A Case Study. *Energies* **2022**, *15*, 1039. https://doi.org/10.3390/en15031039

Academic Editors: Robert Oleniacz and Katarzyna Grzesik

Received: 30 December 2021
Accepted: 27 January 2022
Published: 30 January 2022

1. Introduction

In order to minimize the presence of biodegradable waste in landfills, according to the European Directive [1,2] and the Polish regulations [3,4], mechanical-biological treatment (MBT) plants have been installed. The MBT plants combine the mechanical separation of different fractions present in household waste with the stabilization of the organic matter by means of biological processes. One of the main types of the MBT technology is biodrying, which, in the first stage, directs the waste into the reactor for drying prior to the extraction of the larger fraction intended for the production of RDF [5].

The mechanism of biodrying is a variation of the aerobic decomposition used within the MBT to stabilize the waste, which makes it analogous to composting, but realized in the short term [6,7]. During the process of biodrying, self-heating occurs due to the exothermic reactions of the chemical and biological processes during the transformation of the organic matter [8,9]. During the process, the temperature may rise to even 70 °C [10]. The water removal is supported by both the heat produced by the microorganisms in the biodegradation processes and the air ventilation system. The biodrying process is considered a good solution for a quick reduction in the water content of the MSW [11–14]. The method has the versatile possibilities of using the product of the treatment because it allows one to achieve the required moisture reduction, the volume reduction, and the bulk density enhancement through the effective utilization of the biological heat [11,15,16]. The method is also used for the production of high-quality solid recovered fuel (SRF)—free from hazardous substances and high in biomass content [7].

The degree of the waste drying can be varied by the correct regulation of the process parameters in the reactor [10]. The most important are the airflow rate, temperature, and moisture content. The optimum temperature of the biodrying process is 45 °C; however, even higher temperatures of the mass can be achieved in biodrying [17].

The degree of waste drying can be varied by the correct regulation of the process parameters in the reactor [10], which is applicable when the purpose of the process is to obtain a substrate for the production of an alternative fuel.

The effectiveness of the waste biodrying measured by the moisture decline is about 20–25% [11,16]. The partial decomposition of the organic matter during the biodrying should be under control when the goal is to maintain a high content of organic carbon in order to ensure a high calorific value of the waste, when the aim of the biodrying waste is to produce the RDF. After 14 days of the biodrying process in the reactor, the net heating value (NHV) of the waste could be increased by 20–40% compared to the untreated waste [10].

Most often, researchers describe the results obtained in a laboratory-scale reactor [18–22]. There are only few publications that have presented the results of research on the pilot scale [16,19]. In the literature, there are even fewer articles on bio-drying on an industrial and full scale [13,17,22].

Our research is a novelty due to the fact that the literature lacks the results of research on the biodrying of municipal waste on a full technical scale comparable to our scale, where in our reactor, there is 60 Mg of waste during the research. Moreover, there are no results of research with a similar scope of work to ours. According to the analysis presented in [19], the literature gives only four examples of research on biodrying on an industrial scale. Simultaneously, these are mostly the results from 2004–2009 and do not cover an important parameter such as the NHV of waste before, during, and after the process of biodrying. There are also no results of the NHV in [22], even though the research on biodrying was presented on a technical scale. That work focused on the material balance and the model estimation of water removal [22].

The main aim of this article was an analysis of biodrying, which was determined on the basis of the results obtained from a biodrying reactor working on a full industrial scale. The moisture, temperature, LOI, and NHV were tested during the process of the 14 day biodrying of waste.

2. Materials and Methods

2.1. Mechanical-Biological Treatment Plant

The results presented in this work were obtained from research conducted in the MBT installation in Końskie. This city is located in the center of Poland. The MSW collected from the 158,000-citizen community was the feedstock directed to the plant installations. The MBT plant works according to a two-stage technology where in the first stage, the mechanical operation by sieving (sieve 80 mm mesh) precedes the second biological stage (Figure 1). After the mechanical stage, the 0–80 mm fraction of the MSW undergoes a biodrying process in the reactor for a minimum of 14 days.

The reactor has external dimensions of 6.3 m × 6.7 m × 4.2 m and internal dimensions of 6.1 m × 6.11 m × 4.0 m. The reactor is equipped with a sectional overhead door for loading and unloading the reactor (Figure 2). The walls of the reactor have suitable insulation. The cuboid-shaped, galvanized steel reactor (150 m^3) is equipped with a module for active aeration connected with a bio-filter for removing odors. A set of 4 air supply ducts is installed on the bottom of the chamber, and an exhaust duct is mounted on the top of the chamber. The supply ventilator and the exhaust ventilator work continuously. Thus, during the processing in the drying reactor, the water vaporization is stimulated by a forced aeration system. The increasing temperature resulting from the activity of the microorganisms consequently leads to a gradually decreasing moisture in the waste. The reactor works in a periodic fashion and treats 50–60 Mg of waste at a time. The height of the layer of waste in the reactor is approximately 2.7 m. The reactor is equipped with temperature and moisture sensors (Figure 3).

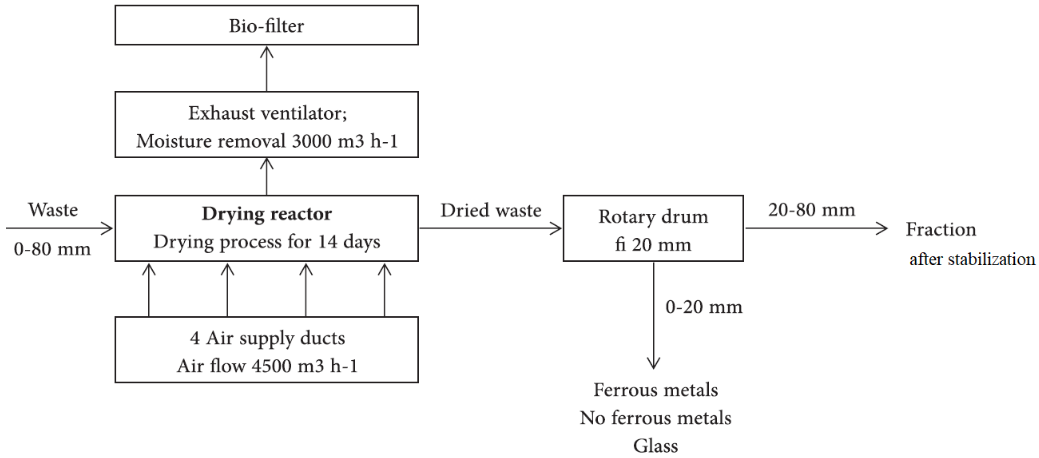

Figure 1. The scheme of the biological stage in the MBT installation.

Figure 2. The industrial reactor—the unloading of waste after 14 days of biodrying.

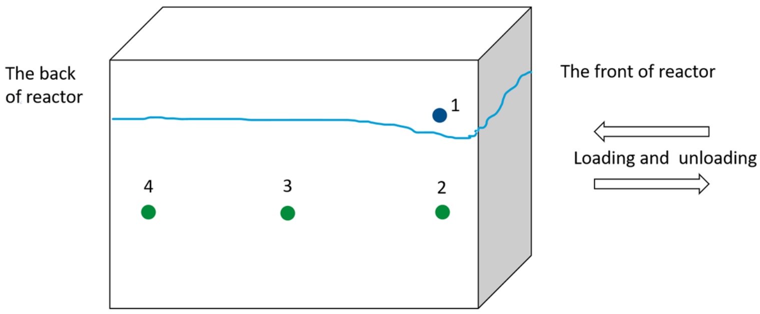

Figure 3. Schematic location of measurement points in the industrial reactor. 1—measurement point of the internal air; 2—measurement point in waste bed in the front; 3—measurement point in waste bed in the middle; 4—measurement point in waste in the back; blue line—the waste fill level of the reactor.

After the biodrying stage, the waste is transported to a rotary drum to remove the 0–20 mm fraction (ballast), as the 0–20 mm fraction is defined as a mineral, considered useless, and should be directed to the landfill site (Figure 1). According to the technology, the 20–80 mm fraction after biodrying and decreasing the moisture content could be considered a potential RDF utilized by thermal methods, provided that the organic carbon content guarantees a sufficiently high heat value.

During the 14 day biodrying, the average daily temperature of the ambient air was from 7.4 °C to 14.9 °C, while the average daily relative humidity of the ambient air was from 62.5% to 92.8% [23].

2.2. Composition of Raw MSW

The annual composition of raw MSW (fraction 0–80 mm) was investigated according to [24,25]. Four 100 kg samples were taken quarterly and, according to the standard in [25], were sieved on a 10 mm mesh-size sieve. The >10 mm fraction was examined for the mass share of plastic, glass, metals, mineral, and biodegradable paper, as well as textiles.

The samples investigated in the physicochemical tests were taken according to the procedure designed for solid recovered fuels [26].

2.3. Testing of the Waste Features in a Biodrying Process

During the 14 days of the biodrying of the waste in the reactor, the variability features in the processed waste were monitored. The temperature and moisture characteristics, both in the mass of the bed and in the air above the bed, were examined. The accuracy of the temperature sensor was +/−1.0 °C. Every waste sample taken from the drying reactor was tested (day by day).

After each day of the reactor operation, the collected waste samples were tested in order to evaluate parameters such as the moisture, LOI, and NHV.

The organic matter content (OM) can be expressed by the organic carbon content, which in the presented experiment was analyzed (in a certain simplification) by the LOI in the samples of the waste during the biodrying process. During the process of biodrying, organic matter undergoes partial decomposition by oxygen microorganisms. Thus, the progress of this process of decomposition can be analyzed with the differences of the LOI values in the subsequent days of the research. The samples for the determination of the LOI were taken from the front, middle, and back of the reactor. The average values of the samples taken after each day of the biodrying were used for the LOI calculations. The samples for the LOI determination were dried at 105 °C [27]. The tests of the LOI were conducted in a muffle furnace (type: M 104, Heraeus Instruments) by incineration at 550 °C for 6 h, using 5 g samples to calculate the average value, according to [28].

The NHV was determined in accordance with [29,30]. The heat of combustion determination was carried out in three replications. The tests for the heat of waste combustion assessment were obtained by mixing the ground laboratory samples obtained from the general tests from different parts of the reactor. Thus, one result of the heat of combustion was obtained for each day of the waste biodrying cycle in the reactor, without a division into the front, middle, or back of the reactor. In total, 42 results were obtained in this research. The tests were conducted with the use of the calorimeter (type: KL-12Mn, producer: Precyzja-BIT) with a measurement accuracy of the temperature increase of +/− 0.001 °C.

3. Results and Discussion

The biodegradable fraction contained in the waste directed to the reactor after summarizing the contribution of kitchen waste and paper was assessed at about 27.7%, but the contribution of the typical combustible waste such as multi-materials, plastic, foils, and fabric was assessed at about 17% (Table 1).

Table 1. The composition of the feedstock (0–80 mm fraction) directed to the reactor [31,32].

Components	Contribution *, % d.m.
Glass	18.0 ± 1.2
<10 mm Fraction	15.7 ± 0.7
Kitchen waste	16.6 ± 3.7
Mineral fraction	14.0 ± 4.8
Paper	11.1 ± 1.6
Multi-material materials	5.8 ± 0.2
Plastic	5.1 ± 0.2
Ceramic	4.9 ± 0.3
Foils	4.7 ± 0.02
Metals	2.4 ± 0.02
Fabrics	1.6 ± 0.03

* ±standard deviation.

The low level of organic waste should be noted as it is the result imposed by the requirements of the segregation at the source of the waste generation after 2012. The mineral fraction (glass, ceramic, mineral fraction, and metals) constituted about 39% of the share (Table 1).

The temperature was recorded in the reactor during the whole waste drying process, as shown in Figure 4. In the early days up to the 4th day, an intense temperature increase was observed, both in the mass of the waste and in the air above the bed. It should be noted that the temperature variation depends on where the temperature sensor is located. A temperature jump to around 70 °C occurred on the first day on the reactor's back wall. This tendency changed due to the reactor being opened every day for the sampling. The average temperature, that is representative of the waste bed is shown by the points for the middle batch of the reactor. These points represent just the highest mean temperatures in the whole cycle. In the following days up to the 9th day included, the temperature dropped to a level of about 30 °C and was then stabilized at this level.

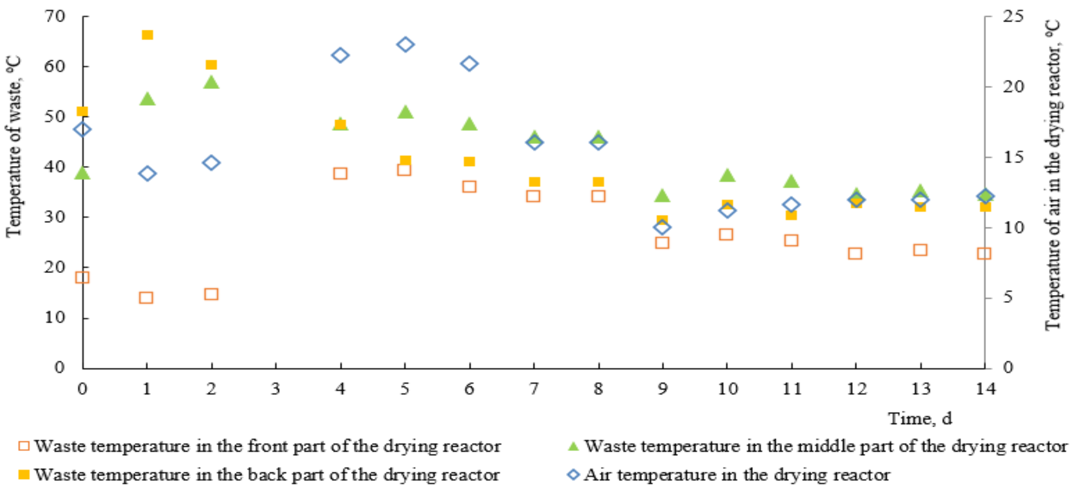

Figure 4. The temperature registered during the 14 days of the biodrying in the three parts of the reactor.

The average moisture content in the waste directed to the reactor was 56.5%. The variability in the moisture of the waste during the 14 days of processing in the reactor is presented in Figure 5. The recorded changes in the waste moisture in the drying process were regular and the moisture decreased from 56.5% to 30–35% (depending on the part of the biodrying reactor) in the final day of drying. Therefore, during the drying cycle, about 24% of the mass of the water was released into the atmosphere. Comparing this result of the drying effect to the result of 20% obtained by Hurka et al. [33], the drying effect in the analyzed reactor was comparable or even slightly better.

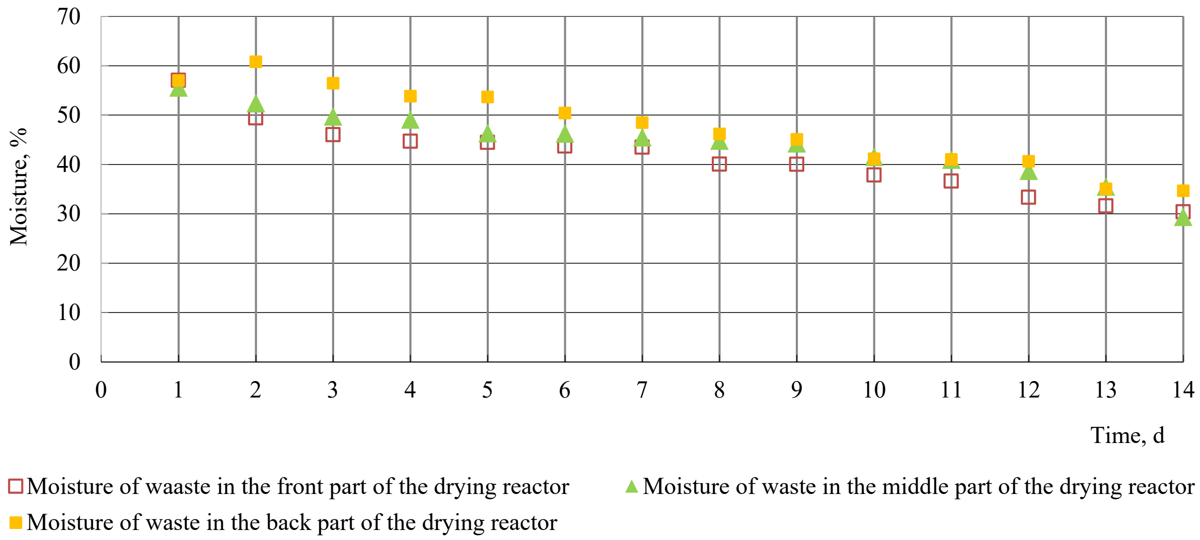

Figure 5. The moisture of the waste registered in the three parts of the drying reactor.

The water loss in the waste mass undoubtedly improved the calorific value of the waste. However, at the same time, a decrease in the share of organic carbon was observed, estimated here using the LOI (Figure 6), which is a consequence of the biomass decay. The value of the LOI of the waste directed into the reactor was about 70%. After 14 days of the biodrying process, the LOI loss was at about 33% to 18% (depending on the part of the mass location in the reactor). A similar reduction in the organic matter was noted by the authors in works [10,22]. During the 14 day biodrying cycle, the highest loss of the LOI to a level of about 37% occurred in the central part of the waste deposit. The lowest decrease in the LOI value to a level of about 52% was recorded in the front part of the reactor. The changes in the LOI parameter were reflected in the changes in the temperature parameter. The higher temperatures in the waste deposit favored the decomposition of the organic matter at a higher level.

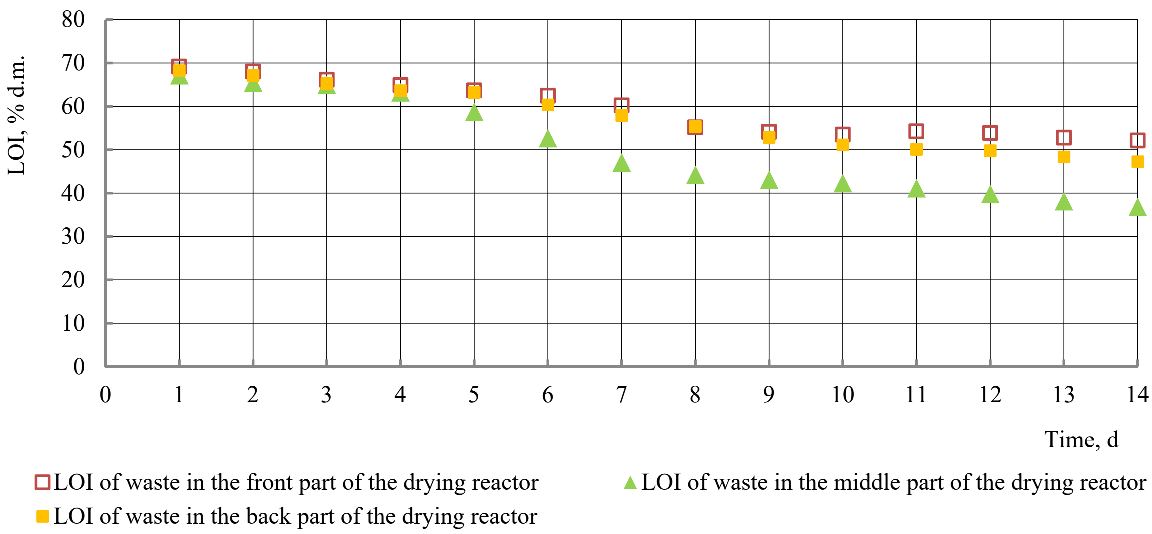

Figure 6. The loss on ignition of the waste registered during the 14 day cycle of the biodrying process in the different parts of the reactor.

As a result of the bio-drying, the NHV of the waste increased by more than 30% in comparison to the primary sample (Figure 7). A similar increase in the NHV of the waste (27%) on the pilot scale was presented by Negoi et al. [34]. However, the bio-drying process according to [34] was twice as long, whereas, according to [20], the biodrying of the waste at 55 °C during the 15 days caused an increase in the NHV of about 45% compared to the primary sample.

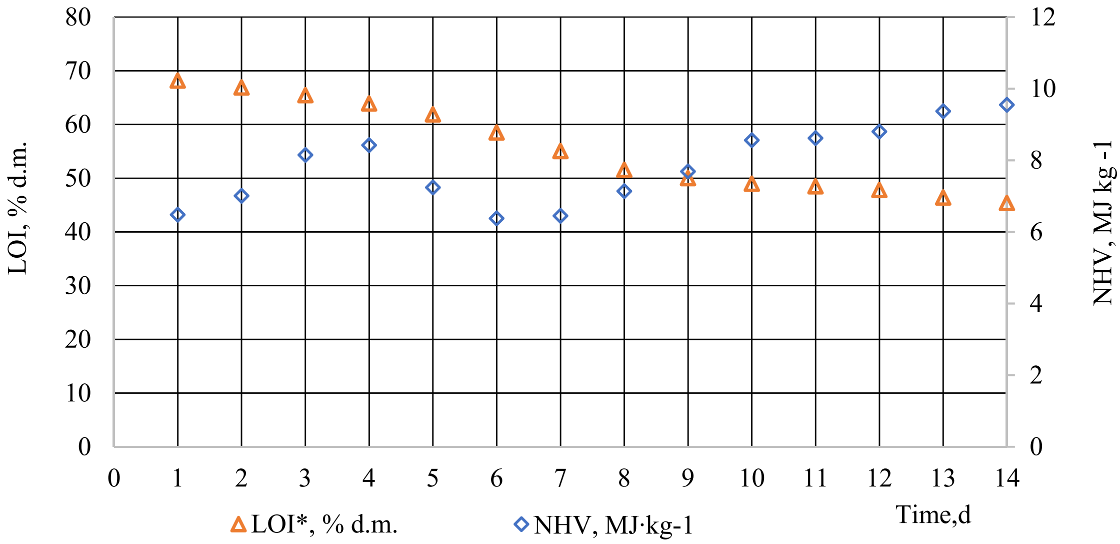

Figure 7. The net heating value and the loss on ignitions registered in the 14 day cycle of the biodrying process. * the LOI is the daily average value recorded from results investigated in the front, middle, and back part of the biodrying reactor.

The results give reason to conclude that, in terms of the NHV of the waste, it is important to properly control the temperature of the process inside the reactor, with minimal effect on the loss of carbon. The changes in the NHV measured in the waste during the 14 day cycle of the biodrying process allow us to confirm the obvious dependence that, along with the decrease in moisture, the NHV of the waste increased. The observed loss in the LOI was caused both by the decomposition of the organic matter as a result of the activity of microorganisms and the combustion of plastics during the standardized test.

4. Conclusions

The results of the research of biodrying in our case study under the industrial conditions on a full scale allow for the conclusions that in the 14 days of the process:

- The moisture of waste decreased to 50%.
- The carbon content expressed as the LOI decreased in waste to 66%.
- The NHV increased by more than 45%.
- The increase in the NHV was affected more by the decrease in moisture in waste than the change in the LOI. The loss of carbon was obtained as the effect of the process of biodegradation.

The results have application value as the plant operator, having at their disposal the controlling of the reactor's ventilation and the temperature inside the reactor, should select the speed of the moisture removal from MSW at such a level as to minimize the LOI and to keep the NHV at the highest level.

Author Contributions: Conceptualization, M.Ż.; methodology, M.Ż. and M.D.; formal analysis, J.L., M.Ż. and M.D.; investigation, M.D.; resources, M.D.; writing—original draft, M.Ż. and J.L.; writing—review and editing, J.L. and M.Ż.; visualization, J.L. All authors have read and agreed to the published version of the manuscript.

Funding: The project is supported by the program of the Minister of Science and Higher Education under the name: "Regional Initiative of Excellence" in 2019–2022 project number 025/RID/2018/19 financing amount PLN 12,000,000.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: Investigations were led using: OXYMAX respirometer ER-10 (Columbus Instruments). Equipment was founded by the MOLAB Project in Kielce University of Technology: POIG 02.02.00-26-023/08-00; and project was supported by the Ministry of High Education.05.0.09.00/2.01.01.01.0004 MNSP.IKIO.14.001.

Conflicts of Interest: The authors declare no conflict of interest.

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