THE IMPACT OF LEACHATE RECIRCULATION DURING AEROBIC BIOSTABILISATION OF UNDERSIZE FRACTION ON THE PROPERTIES OF STABILISATE PRODUCED

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Abstract: The mixed municipal solid waste collected from households is sent for processing in the mechanical-biological treatment plants (MBT). The aim of the study was to evaluate the effect of recirculation of leachate formed in the process of aerobic biostabilisation of undersize fraction (produced from mixed municipal solid waste in MBT process) on selected parameters of stabilised waste (end product of the process). Two variants of the system performance were analysed that is with and without recirculation of leachate into a bioreactor for which 12 and 10 test replicas were performed respectively. The analyses focused on selected technological properties of waste (undersize fraction and stabilised waste) and included morphological composition, density, dry mass, total organic carbon, loss on ignition and respiration activity AT4 (Atmungsaktivität nach 4 Tagen - eng. Respiratory activity after 4 days). The research was conducted in the waste treatment plant in Cracow (Poland) in the period from December 2016 to April 2017. The aerobic biostabilisation process on the MBT system should be based on leachate recirculation technology due to the fact that in this series of tests 83% of the samples achieved all the desired parameters of stabilised waste whereas in the second variant only 30%.

Key Words: mechanical-biological treatment, municipal solid waste, aerobic biostabilisation, stabilised waste

INTRODUCTION

According to the act on the maintenance of cleanliness and order in the municipalities, every municipality is obliged to ensure order and cleanliness on its premises, establish the necessary conditions for its maintenance, embrace all property owners with the municipal waste management system and ensure the construction, maintenance and operation, of its own or common with other municipalities, of the regional municipal waste treatment plant (Journal of Law 2017, item 1289), most often of the mechanical-biological treatment (MBT) plant. In these plants, fractionation such as paper, metal, plastics and glass takes place and which then are recycled and reused (Dias et al. 2014). In MBT plants an oversize fraction exceeding 80 mm (which can be used for example in cement plants as an alternative fuel) is separated on drum or vibratory screens with a mesh size over 80 mm and the undersize fraction below 80 mm is directed to the biological part of the MBT plant in order to be subjected to biodrying, aerobic biostabilisation or methane fermentation (Dębicka et al. 2017). According to Dębicka et al. (2013) biological drying (biodrying) is a relatively new and still unrecognized method of waste management. Biodrying contributes to the reduction of moisture content in waste and to the disappearance of biological degradation resulting in stable and usable fuel (Domińczyk et al. 2012, Flamme 2006, Sugni et al. 2005, Velis et al. 2009). Anaerobic biostabilisation is the process of biological disposal of waste under anaerobic conditions resulting in the production of biogas and digestate, which can then be recovered or disposed of by storage (Jędrzczak and Szpadt 2008, Sikora and Mruk 2016). Aerobic stabilisation is the biological waste disposal process (D8) conducted under aerobic conditions that produces two new wastes - stabilised waste (for landfilling) and compost (for land reclamations). The MBT process is particularly popular in Europe (Adani et al. 2004, Dziedzic et al. 2015), and one of its most important goals is to reduce the amount
of waste deposited in landfills (Abeliotis et al. 2012, Grzesik and Malinowski 2016). MBP plants can also be considered as an alternative to thermal conversion of waste (Soboniak and Bień 2015).

The MBT method does not fully destroy the biodegradable waste (Voberková et al. 2017, Gliniak et al. 2017), but if conducted properly it can obtain the degree of decomposition of biodegradable matter to reach the parameters specified in the Regulation of the Minister of the Environment (Journal of Law 2012, item 1052, Żygadło and Dębicka 2014). The provisions of the regulation are consistent with the provisions of the European Union Directive 1999/31/WE and the European Council Regulation 2008/980/WE (Directive 1999, 2008). In pursuance of the mentioned law regulation regarding the stabilised waste designed for safe landfilling, after the biological step one of the following criteria should be filled (Journal of Law 2012, item 1052):

- The loss of ignition (LOI) of the stabilised waste should be less than 35% related to the dry mass, and the amount of total carbon organic content (TOC) should be less than 20% in the dry mass, or
- The indicator $\Delta S$ of the LOI difference based on comparing the waste before and after the biological treatment should be greater than 40% d.m, or
- Respiration Activity $AT_4$ should be less than 10 mg O$_2$/g d.m.

The share of the undersize fraction obtained from mixed municipal waste depends on the origin of the waste and the season. During spring and summer, the percentage of undersize fraction is lower, while in autumn and winter higher. The average of 550 kg of the undersize fraction (Malinowski 2012) is obtained from 1000 kg of mixed municipal solid waste collected from the countryside. In the aspect of biological processing of the undersize fraction, the share of the biodegradable fraction is crucial. The results of the study carried out by Baran et al. (2016) show that the largest amount of biodegradable waste is produced in the summer and autumn which translates into the rate of biostabilisation of waste.

The aim of the study was to evaluate the effect of leachate recirculation formed in the process of aerobic biostabilisation of undersize fraction (produced from mixed municipal solid waste in MBT plant) on selected parameters of stabilised waste in order to specify the optimum model of functioning of the system in the MBT plant in Krakow (Poland). The optimum process is the one where the parameters set for the produced stabilised waste are obtained in the shortest period of time. The analyses included the selected technological properties of the undersize fraction and stabilised waste that is morphological composition, density, dry mass, total organic carbon (TOC), loss on ignition (LOI) and respiration activity ($AT_4$).

MATERIAL AND METHODS

Description of system

The MBT plant where the study was carried out consists of 4 bioreactors (made of reinforced and acid-resistant concrete). Every bioreactor is a process-independent, sealed module measuring 16 m in length, 7.35 m in width and 6 m in height, equipped with a monitoring system for process parameters, aeration, ventilation and spraying. The front of the bioreactor is closed by a sliding gate. Aeration channels functioning as air supply lines and in the interim as drain pipes as well as six biofilters and control rooms were built into the floor of every bioreactor.

Process leachate is drained by aeration and drainage systems to one of the three underground hermetic septic tanks, and then, after purification on filters it can be pumped into the sprinkler system located under the ceiling of every bioreactor.

The process of biological treatment of waste in bioreactors takes place using active aeration. Process air, after passing through the waste bed, is fed into a common for all bioreactors channel through which, by water scrubber mounted on their roof, is directed to the biofilter system located outside the hall. Biofilters have a special bottom construction that allows for even distribution of process air throughout the bed and penetration through the filter material. Optimal parameters of biofilter performance allow for the neutralisation of odours of about 80–90% of the loaded charge.

Process conditions

The aerobic stabilisation process of the undersize fraction was conducted in 2 variants:

a) without moistening (leachate from the process was not used in the process) for 10 samples;
b) with moistening (closed water circuit) for 12 samples. Moistening was carried out using 100% of the leachate formed in the process to enrich the bed with microorganisms.

The mean weight of the waste loaded into the bioreactors amounted to 242.64 ± 21.29 Mg and the mean height equalled 3.03 ± 0.18 m. For every process, the temperature was monitored using two PT 100 sensors. The temperature record was automatically run every 10 minutes in TeamViewer 12 program allowing for determining the time of completion of the intensive phase and the maximum temperature reached in the bioreactor. The estimated waste processing time amounted to 28 days. During the course of the study, the process was terminated when the temperature was lower than 45 °C that is the moment when the intensive phase of the process ended.

**Sampling for analyses**

The laboratory sample was taken on the basis of the quartering method. Each of the following indications was run in 3 replicates in the laboratories of the Faculty of Production and Power Engineering, University of Agriculture in Krakow and Ferrocarbo. The results of all analyses (30 for non-moistened waste and 36 for moistened waste) were utilised to perform analysis of variance and Tukey's test (STATISTICA 12 package) to determine the significance of the differences between the results of the analyses.

The morphological composition of waste was analysed in 12 categories (groups) of waste (Table 1). The determination of respiration activity that is the AT4 parameter for the undersize fraction and the obtained stabilised waste was enabled by calculating the amount of CO₂ emitted by leachate and measured by OxiTop Control measuring system. The determination includes (EU-Notice number 2001/423/A, Vienna 2002): weighing a sample of about 40g and of assumed humidity, then placing the waste in a glass container of capacity of 2.5 dm³ and a few grams of CO₂ absorber in the lid of the container and then closing it; placing the container in a thermostatic cabinet with a constant internal temperature of 20 °C and checking daily the value of negative pressure. The final value of negative pressure produced in the vessel is converted to the amount of oxygen consumed during the process in accordance with the Clapeyron equation. The other parameters were determined on the basis of the following standards:

- b) PN-EN 14346:2011: Characterization of Waste - Determination of dry mass and water content;
- c) PN-EN 13137:2004: Characterization of waste - Determination of total organic carbon content in waste, sludge and sediments;
- d) PN-EN 15169:2011: Characterization of waste - Determination of loss on ignition in waste, sludge and sediments;
- e) BN-87/9103-04: Characterization of waste - Determination of density.

**RESULTS AND DISCUSSION**

The duration of the process amounted, on average, to 15 ± 2 days. The differences between the average periods of non-moistened and moistened processes were not statistically significant. The volume of water (leachate) introduced into the process in tests with additional bed moistening was on average over 18.5 m³. The mean maximum process temperature came to 60.89 ± 2.96 °C. The temperature of the treated waste for the non-moistened samples was higher and amounted to 61.25 ± 2.71 °C, while for moistened samples it was 60.55 ± 3.26 °C. However, these differences were not statistically significant.

Table 1 presents the average morphological composition of the undersize fraction and the waste processed. The conducted studies indicate that in the morphological composition of the undersize fraction, as a result of the aerobic stabilisation process, the share of fine fraction e.g. the share of waste of particles below 10mm was increased over time from 33.97 ± 3.21% to 41.21 ± 3.16%. The fine fraction predominated in the waste composition. As a result of the process, the amount of organic fraction was reduced from 19.54 ± 3.04% to 12.11 ± 2.81%. The share of the remaining waste fractions as a result of the process did not change by more than about 2%. The reduction of share of the organic fraction and the simultaneous increase of the share of the fine fraction containing mainly mineral waste indicates the correct course of the process and the high activity of microorganisms responsible for the processing of organic waste into inorganic products.
Table 1. Average morphological composition of the undersize fraction on individual days of the process

<table>
<thead>
<tr>
<th>Day of biostabilisation process</th>
<th>3</th>
<th>6</th>
<th>9</th>
<th>12</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Plastic</td>
<td>5.87</td>
<td>6.41</td>
<td>6.12</td>
<td>6.32</td>
<td>5.87</td>
</tr>
<tr>
<td>2 Glass</td>
<td>9.81</td>
<td>10.54</td>
<td>10.41</td>
<td>10.34</td>
<td>10.47</td>
</tr>
<tr>
<td>3 Metal</td>
<td>2.90</td>
<td>3.10</td>
<td>2.40</td>
<td>2.90</td>
<td>2.60</td>
</tr>
<tr>
<td>4 Paper</td>
<td>5.22</td>
<td>4.92</td>
<td>4.84</td>
<td>4.74</td>
<td>4.51</td>
</tr>
<tr>
<td>5 Organic waste</td>
<td>18.67</td>
<td>17.24</td>
<td>14.42</td>
<td>13.29</td>
<td>12.11</td>
</tr>
<tr>
<td>6 Wood</td>
<td>5.42</td>
<td>5.27</td>
<td>4.77</td>
<td>4.42</td>
<td>4.35</td>
</tr>
<tr>
<td>7 Hazardous</td>
<td>1.14</td>
<td>1.35</td>
<td>0.99</td>
<td>0.74</td>
<td>1.47</td>
</tr>
<tr>
<td>8 Hygienic waste</td>
<td>0.48</td>
<td>0.48</td>
<td>0.49</td>
<td>0.63</td>
<td>0.52</td>
</tr>
<tr>
<td>9 Concrete waste</td>
<td>5.90</td>
<td>5.70</td>
<td>6.20</td>
<td>6.30</td>
<td>6.10</td>
</tr>
<tr>
<td>10 Textile waste</td>
<td>8.15</td>
<td>7.96</td>
<td>8.12</td>
<td>7.84</td>
<td>8.21</td>
</tr>
<tr>
<td>11 Fine fraction</td>
<td>34.01</td>
<td>35.02</td>
<td>38.15</td>
<td>40.21</td>
<td>41.21</td>
</tr>
<tr>
<td>12 Other categories</td>
<td>2.43</td>
<td>2.01</td>
<td>3.09</td>
<td>2.27</td>
<td>2.58</td>
</tr>
</tbody>
</table>

Table 2 shows selected physicochemical properties of the waste after the aerobic stabilisation process for the 22 analysed samples. For all bioreactors tested, the results for stabilised waste are as follows:

a) The mean density of waste came to 730 ± 70 kg/m³. There was an increase in the density of waste in comparison to the unprocessed undersize fraction by 170 kg/m³, for the non-moistened samples the density increased by 140 kg/m³ whereas for moistened samples the density increased by 190 kg/m³;

b) The mean dry mass was equal to 86.07 ± 6.16%, which means a 21.47% increase in dry mass in comparison to unsteady waste. In tests carried out without moistening, the dry mass content in the stabilised waste rose by 21.46% and with moistening by 19.82% in relation to the undersize fraction;

c) The mean organic carbon content came to 12.98 ± 3.39% d.m. which indicates a decline of 25.42% d.m. with respect to the C content in the undersize fraction, the carbon content of the non-moistened sample decreased by 25.54% d.m., while for the moistened sample the drop was by 25.32% d.m.;

d) The mean values of loss on ignition (LOI) were 20.18 ± 7.17% d.m., which indicates a decrease of 21.12% d.m., the non-moistened samples showed an average decline of 23.26% d.m., whereas for the moistened samples the mean values decreased by 19.33% d.m.;

e) The mean respiration activity AT4 amounted to 8.16 ± 5.08 mg O₂/g d.m., resulting in reduction of the parameter by 21.12% d.m., the non-moistened samples showed an average decline of 23.26% d.m., whereas for the moistened sample the drop was by 23.86 mg O₂/g d.m. Statistical analysis of the research results showed that the tested biostabilisation variants differed in a statistically significant manner only in the case of AT4 parameter.

In the non-moistened variant as many as 7 in 10 samples did not reach the desired AT4 parameter. The other parameters described in the MBP Regulation (Journal of Law 2012, item 1052) that is the loss on ignition as well as the organic carbon content, were achieved. In the case of closed circuit of leachate, only 1 out of 12 cases did not achieve the AT4 parameter and subsequently LOI. The total organic carbon content for all 22 samples tested reached the value expressed in MBP Regulation (Journal of Law 2012, item 1052). The obtained results of biostabilisation are parallel to those of Adani et al. (2004) and Dziedzic et al. (2015) but are considerably higher than those obtained by Baran et al. (2016) and Dębicka et al. (2014).
**Table 2 Selected physical and chemical properties of the waste after the aerobic biostabilisasion process**

<table>
<thead>
<tr>
<th>Sample type</th>
<th>Density [Mg/m³]</th>
<th>Dry mass [%]</th>
<th>TOC [% d.m.]</th>
<th>LOI [% d.m.]</th>
<th>AT4 [mg O₂/g d.m.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undersize fraction</td>
<td>0.56</td>
<td>64.60</td>
<td>38.40</td>
<td>41.30</td>
<td>28.80</td>
</tr>
<tr>
<td>Mean</td>
<td>0.73 ± 0.07</td>
<td>86.07 ± 6.16</td>
<td>12.98 ± 3.39</td>
<td>20.18 ± 7.17</td>
<td>8.16 ± 5.08</td>
</tr>
<tr>
<td>Mean for samples 1–10 (without moistening)</td>
<td>0.70 ± 0.04</td>
<td>88.06 ± 3.28</td>
<td>12.86 ± 2.86</td>
<td>18.04 ± 4.33</td>
<td>12.02 ± 3.83</td>
</tr>
<tr>
<td>Mean for samples 11–22 (with leachate being recycled)</td>
<td>0.75 ± 0.08</td>
<td>84.42 ± 7.55</td>
<td>13.08 ± 3.90</td>
<td>21.97 ± 8.66</td>
<td>4.94 ± 3.52</td>
</tr>
</tbody>
</table>

**CONCLUSION**

In waste processing, the organic fraction share and the organic carbon content diminished in its morphological composition which indicates the high activity of microorganisms in the analysed process and its correct course. The stabilised waste after all processes reached at least one of the three parameters that must be met by waste after the biological stabilisation process. In aerobic stabilisation without moistening, the stabilised waste reached all parameters in only 3 tests, whereas in case of leachate recirculation it was feasible to achieve stabilised waste of the desired parameters over the period of 15 ± 2 days in 83% of samples. In two cases the process was completed on the twelfth day.

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**REFERENCES**


