Autothermal Drying of Sewage Sludge and Organic Fraction of Municipal Solid Waste in Batch Bioreactor

Liliana Krzystek, Agnieszka Zawadzka, Stanisław Ledakowicz,
Department of Bioprocess Engineering, Faculty of Process and Environmental Engineering,

CONTACT
Technical University of Lodz, Wólczanska Str. 213, 90-924 Lodz, Poland.
Corresponding Author: Liliana Krzystek, email: krzystek@wipos.p.lodz.pl

EXECUTIVE SUMMARY

Since sewage sludge is very hydrated, its thermal drying process is energy consuming and hence costly. Using such biological methods as, for instance, composting or biodrying is an interesting alternative for their utilization.

Composting and biostabilization processes lead to the complete degradation of easily biodegradable organic matter, while in biodrying, the heat produced is used to dry the organic waste material, preserving its calorific value. In the case of biodrying the thermal energy released during aerobic decomposition of organic matter is used to dry the waste and produce solid recovered fuel. In biodrying, the main drying mechanism is convective evaporation, using heat generated during the aerobic biodegradation of waste components and facilitated by the mechanically supported airflow. (Sugni et al., 2005, Velis et al., 2009).

The process of biodrying remains a relatively new technology and has been the focus of interest of few scientists so far, first and foremost, Adani et al., 2002, Sugni et al., 2005.

The aim of the study was to carry out the process of autothermal drying of the mixture of sewage sludge and organic household waste of high initial moisture content in order to obtain biofuel of the satisfactory energy content.

To carry out the process of biodrying a drying tunnel of volume 240 dm³, which had been isolated with polyurethane foam so as to prevent heat losses, was used. The autothermal drying tunnel was equipped with sensors to measure the temperature of the composting biomass in the top and bottom layer of wastes, the temperature of the air over the composting biomass and the temperature and humidity of the outlet air. The temperature of composting biomass as well as the temperature and humidity of inlet and outlet air were continuously measured online.

The air at a temperature of about 35°C was supplied to the reactor through a duct heater and in-line duct fan of capacity 86.35 m³/h only at the beginning of the process. The operation time of the in-line duct fan was equal to 2h or 6h depending on the process. The exhaust fan was used to remove humid air at the rate of 27.34 m³/h. The exhaust fan operation time during
the process depended on the temperature of composting wastes and was controlled automatically by a computer program.

As a result of the autothermal biodrying process the moisture content of organic waste decreased by 50% at the initial moisture content about 800 g$_{\text{water}}$/kg wet weight. The temperature of the composting biomass reaching about 45°C was generated despite the fact that the inlet air was of ambient temperature.

In the tested processes the carbon content as well as the calorific value and the heat of combustion of the dried material were calculated. The results indicate that the material obtained is characterized by a satisfactory energy content and may be applied as biofuel.

INTRODUCTION

Sewage sludge is formed during mechanical, biological and chemical treatment of wastewater. This causes the generation of large amounts of sewage sludge and its management becomes a growing problem. The applied biological methods of management are based on sewage sludge treatment using such biological methods as, for instance, composting or biodrying. Composting of sewage sludge alone or in combination with municipal waste is a multi-functional process aimed at its bio-stabilization and the production of material which can be used for agricultural purposes, or can be stored safely in a landfill. The difference between composting and biodrying depends on the values of control parameters such as temperature, oxygen content, air flow rate and waste moisture content (Tita et al., 2007). Air flow rate influencing biomass temperature affects drying process, while the degree of organic matter degradation affects the calorific value and stability of the final product (Adani et al., 2002). In the case of biodrying the thermal energy released during aerobic decomposition of organic matter is used to dry the waste and produce solid recovered fuel. In biodrying, the main drying mechanism is convective evaporation, using heat generated during the aerobic biodegradation of waste components and facilitated by the mechanically supported airflow. (Sugni et al., 2005, Velis et al., 2009).

The moisture content in the biomass is removed in two steps. First there is the evaporation of water molecules from the dried biomass surface to the surrounding and then this evaporated water is transported through the dried waste mass by the use of flowing air and finally it is removed with exhaust gases (Sugni et al., 2005, Velis et al., 2009).

The process of biodrying has been the focus of interest of very few scientists so far. In the literature the research concerning biodrying of organic fraction of municipal solid wastes with low initial moisture content predominates. Adani et al., 2002, Sugni et al., 2005 in their investigations used municipal solid waste of low initial moisture content equal to 410 g kg⁻¹, which then was dried with the air of temperature 40°C. The reduction of moisture content to the level of 205 g kg⁻¹ was achieved. Except these two papers the literature data on investigations of biodrying of sewage sludge mixture and municipal solid waste mixture of high initial moisture content have not been found yet.

The aim of the study was to carry out the process of autothermal drying of sewage sludge mixture and organic household waste mixture of high initial moisture content in order to obtain biofuel of the satisfactory energy content.
MATERIALS AND METHODS

Experimental Set-Up
Experiments were performed in the laboratory scale using a horizontal reactor of 240 dm³ of total capacity. The reactor was insulated with polyurethane foam to prevent heat losses, Fig.1.

The adiabatic reactor was equipped with sensors to measure: the temperature of the composting biomass in the top and bottom layer of wastes, temperature of air over composting biomass, temperature and humidity of inlet and outlet air. Additionally, a air velocity transmitter measuring air flow rate was installed in the bioreactor. Temperature of composting waste as well as the temperature and humidity of inlet and outlet air were continuously measured online. Additionally, the temperature and humidity of the air in the laboratory where the process was carried out, were measured. The biofilter was used to reduce odor impact in the laboratory.

The air of temperature of about 35°C was supplied to the reactor through a duct heater and in-line duct fan of capacity 86.35 m³/h only at the beginning of process. The operation time of in-line duct fan was equal to 2h or 6h depending on the process. The exhaust fan was used to remove humid air at the rate of 27.34 m³/h. The exhaust fan operation time during process was controlled automatically by a computer program depending on the temperature of composting waste.

Figure 1. Schematic diagram of the batch reactor. 1 – Composting biomass, 2 – Drying tunnel, 3 – Polyurethane foam, 4 – Duct heater, 5 – In-line duct fan, 6 – Inlet air, 7,8 Temperature sensors of composting biomass, 9 – Temperature sensor of biomass over compost, 10 – Biofilter, 11 – Outlet air, 12 – Exhaust fan, 13 – Temperature and moisture sensors of outlet air, 14 – Air velocity transmitter, 15 – Temperature and humidity sensor of inlet air.

In the investigation aerobic sludge form Municipal Wastewater Treatment Plant in Lodz, dewatered sludge from Municipal Wastewater Treatment Plant in Zgierz, Poland as well as shredded (2-4 cm) fraction of solid municipal wastes and plant structural material were used. The mass of waste supplied to the drying tunnel was about 21 kg.

The content of dry mass and dry organic mass were determined by gravimetric method (APHA, 1992).

The heat of combustion and calorific value of the composted material were determined using a KL-12Mn calorimeter according to Polish Standards PN-73/G-04513.
RESULTS

A series of experiments of autothermal drying have been performed. This paper presents results of three series, which differed in the amount of supplied air and the composition of composting biomass.

In the process 1 as a substrate aerobic sludge, organic fraction of solid municipal waste and plant structural material with the initial moisture content of 860 g kg⁻¹ were used. During this process the air of the temperature of 35°C was being supplied to the drying tunnel for 6 hours.

In process 2 dewatered sludge, organic fraction of solid municipal waste and plant structural material with the initial moisture content of 801 g kg⁻¹ were used. The air of the temperature of 35°C was being supplied for only 2 hours.

To make a comparison process 3 was conducted. In this process only organic fraction of solid municipal waste and plant structural material with the initial moisture content of 803 g kg⁻¹ were used. Similarly to the process 1 the air of the temperature of 35°C was being supplied for 6 hours.

Duration times for processes 1, 2, 3 in series 1 were 15, 11 and 16 days respectively.

Figure 2 shows the typical changes of biomass temperature in the top and bottom layer of composting waste and the changes of the temperature of the air in the reactor over the composting biomass and the changes of the temperature and humidity of outlet air in the process 1.

Initial temperatures in both layers (top and bottom) were at the level of 20°C -23°C. On subsequent days of the process, one could observe the increase of temperatures in both layers. The highest value of the biomass temperature was attained on the ninth day of the process in the top layer (ca. 45°C). During the process high temperature differences of the order of 6°C-9°C between both layers were observed. On the last days of the process the temperature decrease of both layers up to ca. 21°C was reported.

The mean value of air temperature over the compost was 19°C. On the first days of the process the values of the outlet air humidity reached the value of ca. 54%. On subsequent days of the process the humidity increased up to ca. 63%. On the eighth day this parameter started to decrease rapidly reaching the value of 45%.

The temperature of the outlet air was similar to the temperature of air over the compost in the tunnel. The mean value of the outlet air was ca. 21°C.
In process 2 lower values of composting biomass temperature were obtained (fig. 3). At the beginning of the process the temperature of both layers attained the values: top layer 18°C, bottom layer 19°C. On the subsequent days the temperature in both layers increased, however the temperature of the bottom layer remained lower by ca. 2°C. On the sixth day of the process the highest values of the temperatures of both layers were observed. The temperature of the top and bottom layer were ca. 40°C and 38°C respectively. On the subsequent days the decrease of the temperatures was observed. In the final phase of the process both temperatures reached the value of ca. 20°C. In this process one could not observe the significant temperature differences between the layers. This temperature difference was ca. 2°C-3°C.

In the process 2 higher values of the outlet air humidity were recorded comparing to the process 1. On the initial days of the process humidity reached the level of ca. 66%. The highest value of the outlet air humidity was observed on the fourth day of the process and was equal to 70%, while on the last day it was ca. 56%.

The mean value of the outlet air temperature in the process 2 was ca. 21°C, while of the air temperature over compost - ca. 20°C. In this process these both temperatures were on the same level, similarly to the process 1.
In the process 3 higher (than in process 1 and 2) values of the temperature of composting waste were reported (fig. 4). On the initial days of the process the temperatures of the top and bottom layers were ca. 19°C and ca. 20°C respectively. On subsequent days one could observe the increase of temperatures in both layers. The highest values of the biomass temperature were attained on the eighth day of the process in the top layer- 50°C and in bottom one- 46°C. On the eleventh day temperatures reached the same value of ca. 44°C. On the last days of the process both temperatures decreased up to 20°C in the top layer and 18°C in the bottom one. The temperature difference between these two layers was ca. 2°C-3°C.

The mean value of the temperature of air over compost in this process was ca. 25°C. However, the mean value of the outlet air temperature was ca. 23°C. The difference in these temperatures was of the order of 2°C-3°C.

In comparison with processes 1 and 2, in the process 3 the higher values of the outlet air humidity were noted. On the initial days of the process the value of outlet air humidity was equal to ca. 41%. On the subsequent days, rapid increase of this parameter was observed, up to 78%, and next its decrease up to 40% on the last day of the process was reported.
Figure 4. Temperature in the top and bottom biomass layers and air temperature over composting biomass and temperature and humidity of outlet air in experiment no 3.

Table 1 presents the results of autothermal drying of all three processes. The lowest final value of the moisture content was obtained in the process 3, where sludge had not been added to the composting wastes. In the process 2, where dewatered sludge was composted together with organic fraction, the moisture removal degree was the lowest. However, in this process the air of the temperature of 35°C was being supplied only for 2 hours.

In the process 1 the highest values of combustion heat and calorific value were obtained. Also the highest value of carbon was attained in this process. In all performed processes hydrogen content was stated to be on the same level. In the process 3, in turn, the highest value of nitrogen in the composting biomass was obtained. In all processes trace amount of sulphur was stated.

Table 1. Biodrying process results.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Experiment no 1</th>
<th>Experiment no 2</th>
<th>Experiment no 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial moisture content</td>
<td>860 g kg⁻¹</td>
<td>801 g kg⁻¹</td>
<td>803 g kg⁻¹</td>
</tr>
<tr>
<td>Final moisture content</td>
<td>479 g kg⁻¹</td>
<td>510 g kg⁻¹</td>
<td>380 g kg⁻¹</td>
</tr>
<tr>
<td>C</td>
<td>44,19%</td>
<td>42,05%</td>
<td>43,12%</td>
</tr>
<tr>
<td>H</td>
<td>5,79%</td>
<td>5,84%</td>
<td>5,83%</td>
</tr>
<tr>
<td>N</td>
<td>1,96%</td>
<td>2,82%</td>
<td>3,12%</td>
</tr>
<tr>
<td>S</td>
<td>0,05%</td>
<td>0,09%</td>
<td></td>
</tr>
<tr>
<td>Heat of combustion</td>
<td>17,45 kJ/g</td>
<td>16,53kJ/g</td>
<td>16,02kJ/g</td>
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<tr>
<td>Calorific value</td>
<td>16,17 kJ/g</td>
<td>15,25kJ/g</td>
<td>14,73kJ/g</td>
</tr>
</tbody>
</table>
CONCLUSION

A proper control of biodrying process parameters makes it possible to dry composting biomass in a short time or to produce good-quality compost. It is very important to keep air supplies on a high level, which ensures a decrease of water content in the waste and oxidation of the composting biomass.

In the performed processes of autothermal drying moisture loss on the level of ca. 50% was obtained. The highest moisture loss was reported in the process 3, where organic fraction was composted alone. The addition of the sludge to the composting waste caused the increase of final moisture content.

When comparing the final moisture content in processes 2 and 3, one can notice that the amount of the supplied air plays a significant role. In these processes, the initial moisture content was similar, while the final moisture content in process 2 was higher by ca. 30% in comparison with the process 3, where the initial amount of air supplied was three times higher.

In the process 3, the highest temperatures of the order of 50°C were obtained. In the process 1, where the amount of supplied air was the same, one did not obtain such temperatures as in process 3. It could have been caused by much higher initial moisture content. However, in process 2, where the amount of the supplied air was lower, the temperatures of the composting biomass were lower by ca. 4°C -5°C in comparison with the process 1.

In the performed processes the air was supplied only from one direction, what could have caused high temperature gradient in the top and bottom layers in the process 1 (6°C -9°C).

In the process 3, where the amount of supplied air was the same as in the case of the process 1, but the moisture content was lower, the temperature difference of both layers reached the lower level of 2°C -3°C. Similarly, in the process 2 with lower amount of the supplied air (than in processes 1 and 3), the difference between temperatures in composting waste layers was low and equal to 2°C-3°C (as it was in the process 3). It suggests that with high initial moisture content not only the amount of the supplied air is important, but also the way of its distribution.

In performed processes the air temperatures over compost and temperatures of the outlet air remained on the same level.

For all processes satisfactory values of the heat of combustion (the mean value 16,6kJ/g) and the calorific value (the mean value 15,38kJ/g) were attained. It confirms that the obtained product is a biofuel of good energy content.

ACKNOWLEDGEMENTS

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REFERENCES


