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AUTOTHERMAL DRYING OF ORGANIC FRACTION OF MUNICIPAL SOLID WASTE

In order to take advantage of heat released during composting, the autothermal drying process requires the maintenance of adequate air flow combined with temperature. The aim of this paper was to construct a drying tunnel enabling the automatic control and regulation of the basic process parameters for biomass drying (organic fraction of municipal solid waste together with plant structural material) to obtain biofuel.

In the course of investigations, various constructions of a drying tunnel were tested. The best results were accomplished for a horizontal reactor with the automatic regulation of air flow. About 50% reduction of moisture content and dry mass on the level of 0.53 $kg_{dry\ mass}/kg_{wet\ weight}$ were obtained. The heat of combustion of dried waste and its calorific value were 12.28 kJ/g waste and 10.98 kJ/g waste, respectively.

1. INTRODUCTION

The latest EU policy on waste management (documents 91/156/EEC; 91/689/EEC; 94/62/EU) recommends the recycling of material and energy products and waste treatment before landfill disposal. For this reason the biological processes leading to compost production, stabilized product, and refuse derived fuel have come to be considered of general interest. Composting, biostabilization and biodrying processes have been exhaustively studied and reviewed in the past. In particular, the use of biomass for energy production is nowadays regarded as of general relevance above all in the case of municipal solid waste (ADANI et al. 2002). The process of biodrying could be a good solution for municipal solid waste management, allowing the production of fuel with a promising energy content.

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The influence of biomass temperature on biostabilization-biodrying of municipal solid waste has indicated that appropriate management of the process parameters (air flow rate and biomass temperatures) could achieve biomass drying in very short times 8–9 days (SUGNI et al. 2005). Composting and biostabilization processes lead to the complete degradation of easily degradable organic matter in order to reach biostabilization and humidification (compost). On the other hand, biodrying dries the biomass while preserving calorific power (ADANI et al. 2002).

The autothermal degradation of organic matter in which stable, easily storable biofuel is produced is an option particularly interesting from the economic point of view.

The process of biodrying has been the focus of interest of few scientists so far, first and foremost ADANI et al. 2002, SUGNI et al. 2005. These authors (ADANI et al. 2002 and SUGNI et al. 2005) in their investigations utilized a specially constructed cylindrical, insulated reactor of 148 dm^3 capacity. ADANI et al. (2002) examined the influence of biomass temperature on the biodrying process. The initial moisture content of the municipal solid wastes was only 410 $g_{H_2O}/kg_{\text{wet weight}}$, and the temperature of supplied air was 40 °C. In the course of their research Adani et al., (2002) obtained a high temperature of 70 °C and good results of calorific value – 10 531 $kJ/kg_{\text{wet weight}}$. The authors observed that biodegradation and biodrying processes were inversely correlated: fast biodrying produced low biological stability, in particular, lower temperatures were obtained by increasing air flow rate and vice versa.

SUGNI et al. (2005) in the same reactor examined the influence of alternate air flow on the process of biodrying. Maintaining the air supply on an appropriate level they also obtained high values of temperature of composted waste (60 °C). In the course of their investigations they had an opportunity to observe that a lack of mixing and supplying the air from only one direction contribute to the appearance of temperature gradients, resulting in a lack of homogeneity in the moisture and energy content of the final product.

However, the course of biodrying is not fully known, in particular the investigations of biodrying of organic matter of high initial moisture content. Furthermore, ADANI et al. (2002) SUGNI et al. (2005) did not present an accurate description of the construction of the reactor applied in their investigations. Considering the results of their research which confirmed the relevant influence of mixing and the amount of the supplied air, the examinations were undertaken with a view to construct a reactor allowing one to carry out the processes of drying of waste of high initial moisture content.

The main aim of this work was to construct a drying tunnel to carry out the autothermal process of drying of the solid waste from households of very high initial moisture content, allowing to obtain biofuel of satisfactory energy content.

2. MATERIALS AND METHODS

2.1. EXPERIMENTAL SET-UP

In the study three different constructional solutions of a periodic reactor for carrying out the process of autothermal drying were tested: 1. a vertical reactor of total capacity 120 dm^3 (No. 1); 2. a horizontal rotating reactor of total capacity 120 dm^3 (No. 2) and 3. a horizontal reactor of total capacity 240 dm^3 (No. 3). Each of the tunnels was made of plastic and insulated with polyurethane foam to prevent heat losses (figures 1, 2 and 3).

The vertical reactor was located on a metal stand which enabled its turning (figure 1).

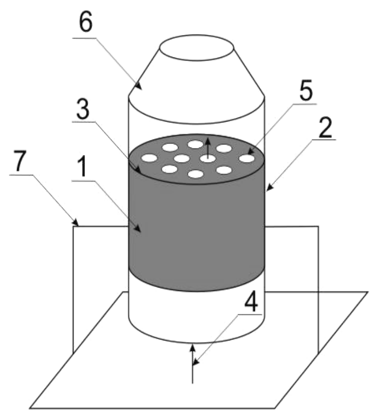

Fig. 1. Schematic diagram of autothermal drying tunnel No 1: 1 – Drying tunnel, 2 – Polyurethane foam, 3 – Cover with holes, 4 – Inlet air, 5 – Outlet air, 6 – Biofilter, 7 – Stand

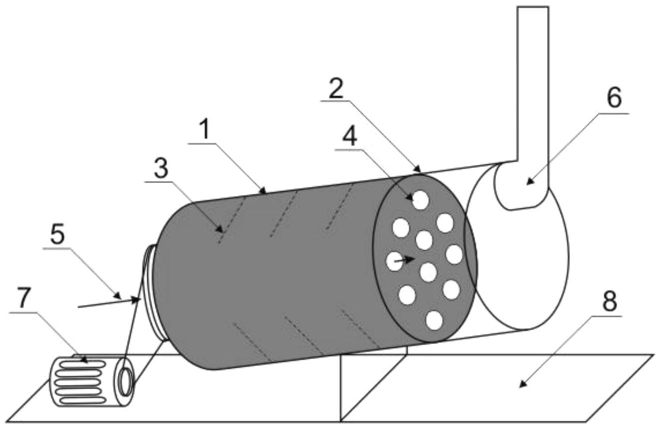

Fig. 2. Schematic diagram of drying tunnel No. 2: 1 – Polyurethane foam, 2 – Cover with holes, 3 – Metal bar, 4 – Outlet air, 5 – Inlet air, 6 – Biofilter, 7 – Engine, 8 – Stand

Reactor No. 2 was turned automatically by the engine. In the centre of the bioreactor No. 2 an agitator was installed and at the internal walls metal bars were located to ensure appropriate mixing of composting biomass (figure 2).

The air supplied to reactors No. 1 and 2 was of temperature of about 23 °C. The air was supplied to the reactors 1 and 2 every hour for 15 minutes. Within the course of biodrying processes carried out in reactors 1 and 2 the temperature and moisture of composting waste were measured.

A horizontal reactor No. 3 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 outlet air (figure 3).

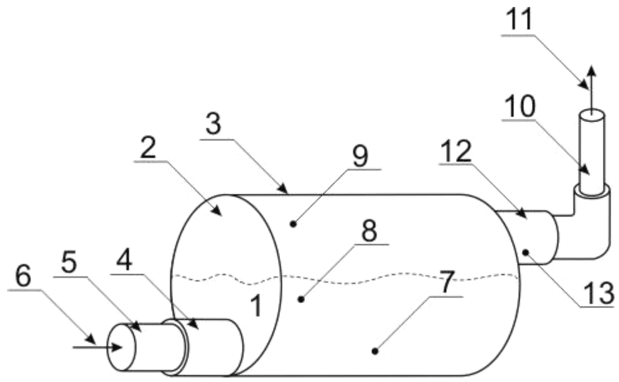

Fig. 3. Schematic diagram of the autothermal drying tunnel No. 3:
1 – Composted biomass, 2 – Drying tunnel, 3 – Polyurethane foam, 4 – Duct heater,
5 – In-line duct fan, 6 – Inlet air, 7, 8 – Temperature sensors of composted biomass,
9 – Temperature sensor of biomass over compost, 10 – Biofilter, 11 – Outlet air, 12 – Exhaust fan,
13 – Temperature and moisture sensors of 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 of temperature of about 30 °C was supplied to reactor 3 through a duct heater and in-line duct fan of capacity 86.35 m^3/h only per 1 h at the beginning of the process. The exhaust fan was used to remove humid air at the rate of 27.34 m^3/h. The exhaust fan operation time during the process was controlled automatically by a computer program depending on the temperature of composting wastes.

The biofilters were used to reduce odor impact in the laboratory.

2.2. ANALYTICAL PROCEDURES

In the investigations the mixture of household wastes and plant structural material of high moisture content was used as a substrate. On the basis of the analysis of the morphological composition of solid municipal waste for the city of Łódź, Poland, the model composition of composting biomass of wastes (shredded ~ 3 cm) was prepared (LEDAKOWICZ et al. 2004). The mass of waste supplied to reactors was about 13 kg (reactor 1 and 2) and about 25 kg (reactor 3). The ratio of source separated organic waste to structural material which was supplied to the drying tunnel was 1.5–1.7:1.

The content of dry mass and dry organic mass was 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. The elementary analysis was made according to Polish Standards PN-ISO-13878/2002 in a NA-2500 elementary analyzer (CE Instruments).

The examinations of pyrolysis and gasification of dried waste were carried out at the Institute of Power Engineering in Warsaw (ILMURZYŃSKA and CELIŃSKA 2008).

3. RESULTS AND DISCUSSION

In the study the investigations of autothermal drying of the mixture of household wastes and plant structural material were carried out. Table 1 presents the results of the examinations of moisture content for the experiments performed in three different constructional solutions of the reactors.

Table 1

Moisture content of composting biomass in reactors No. 1, 2 and 3

Reactor	Moisture content of composting biomass	
	At the beginning of autothermal drying process	At the end of autothermal drying process
	$kg_{H_2O}/kg_{wet\ weight}$	$kg_{H_2O}/kg_{wet\ weight}$
1	0.86	0.53
2	0.80	0.61
3	0.85	0.46

Duration of the composting and drying cycle in reactor No. 1 was 11 days. The initial moisture of waste attained the value of 0.86 $kg_{H_2O}/kg_{wet\ weight}$. The final moisture value was equal to 0.53 $kg_{H_2O}/kg_{wet\ weight}$, (Table 1). In this test cycle one could observe a decrease of moisture by about 30%. Figure 4 shows the temperature mean values of composting biomass in reactor 1.

Within the first three days of the drying process an increase of temperature can be noticed. The highest temperature recorded during the process was 33 °C. It must be added that it was attained on the 2nd and 3rd day of the process. After four days the temperature decreased to 28 °C. Afterwards, the repeated increase by 2 °C was observed. On the 8th and 9th day the temperature started to decrease to the value of 26 °C. On the 11th day of the process the repeated increase in temperature was observed and its value was 32 °C. Low temperatures obtained in this test series and high final moisture of biomass as well as the observed increase in the temperature were probably caused by a lack of the appropriate mixing and air flow.

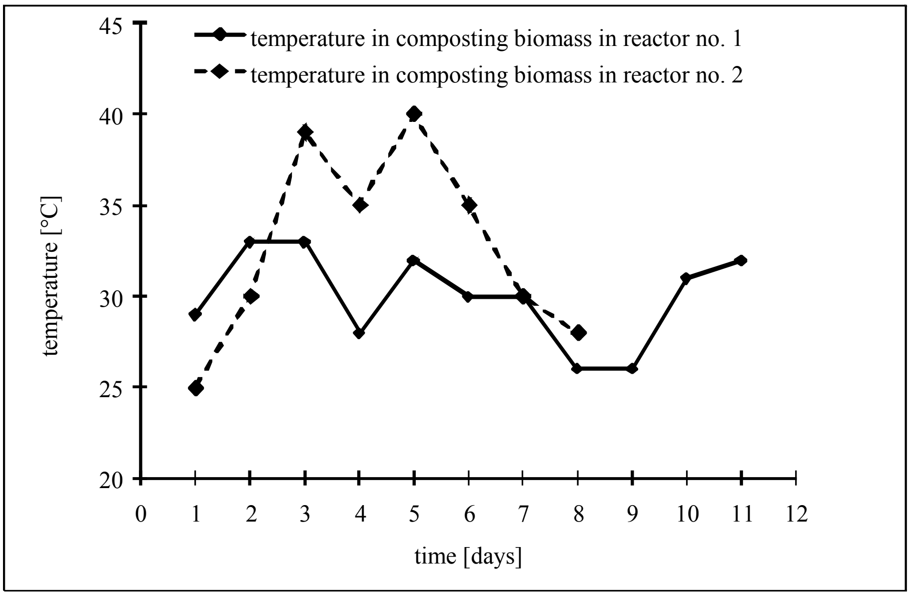

Fig. 4. Temperature in composting biomass in reactors No. 1 and 2

Duration of the composting and drying cycle in reactor No. 2 was 8 days. In Table 1 there are presented the values of moisture content at the beginning and at the end of the process for reactor No. 2. The initial moisture of biomass in this test series was 0.80 $kg_{H_2O}/kg_{wet\ weight}$. In this test cycle a satisfactory decrease in moisture was not attained, the final moisture content was 0.61 $kg_{H_2O}/kg_{wet\ weight}$. Furthermore, a decrease in moisture by about 20% was obtained.

The character of changes of the temperature mean values of composting biomass in reactor 1 and 2, showed in figure 4, was similar. On the 1st day of the process the temperature in the reactor No. 2 was 25 °C. On the 3rd day one could observe an increase in temperature up to 39 °C. On the 4th day of the process a decrease in temperature to 35 °C was noticed. The highest temperature in this test cycle (40 °C) was obtained on the 5th day. On subsequent days a decrease in temperature can be noticed. On the last day of the investigations the temperature of biomass reached the value of

28 °C. It is highly probable that the observed increase in temperature, similarly to reactor 1, is caused by a lack of the appropriate mixing and air flow.

In reactor 2, analogously to reactor 1, a similar level of decrease in moisture content of waste mass (about 20%) was obtained. Nonetheless, higher temperatures were recorded (40 °C), which was due to the better process conditions for composting than in reactor 1. Notwithstanding, those results are not satisfactory due to the fact that the final waste moisture content was very high.

The construction of reactor 3 is an improved modification of reactor No. 2. Duration of the biodrying processes in reactor No. 3 was 10 days. In the test cycles high temperatures of the composting biomass were obtained. Figure 5 shows typical temperature changes in the top and bottom waste layer for a typical process.

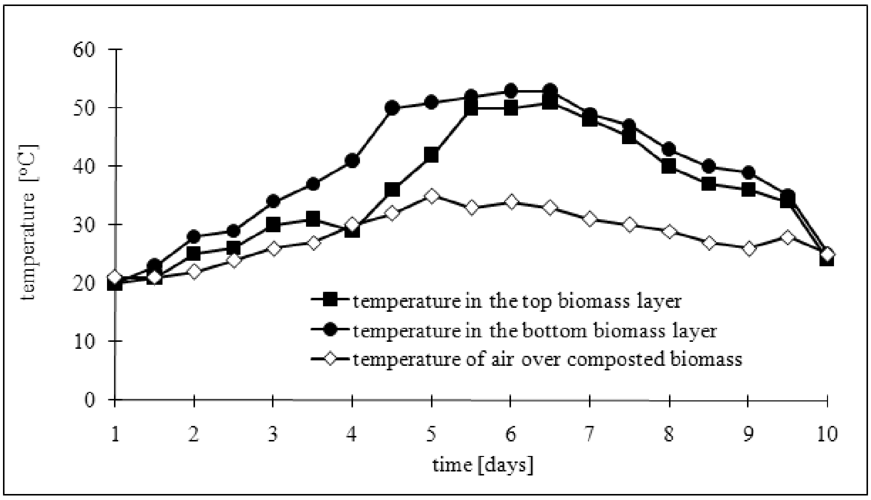

Fig. 5. Temperature in the top and bottom of waste mass layer in reactor No. 3

On the first days of the composting process, the temperature in the bottom layer was higher and amounted to about 23 °C, while temperature of the top layer was about 21 °C. On the 6th day of the process, a temperature growth was observed in both layers. The highest temperatures, reaching 53 °C, were obtained in the bottom waste layer. The temperature in the top layer was lower by about 2 °C in this period. At the end of the process, a decrease of temperatures in both layers to the level close to inlet air temperatures, i.e. 21 °C to 23 °C, was observed. The temperature of the top layer was 23 °C, while that of the bottom layer about 25 °C. On the 10th day of the cycle, temperature of the bottom layer was on a higher level. The difference of temperature of the bottom and top layer was not too high and attained the values ranging from 2 °C to 5 °C, which indicates a satisfactory level of homogeneity in the moisture and energy content of the final product.

Above the composting biomass, air temperature in the reactor was lower than the waste composting temperature. The initial value of this parameter was about 21 °C. The highest air temperature was around 34 °C. At the end of the processes, the temperature dropped to 23–25 °C.

Typical changes in the outlet air humidity for composting waste are shown in figure 6.

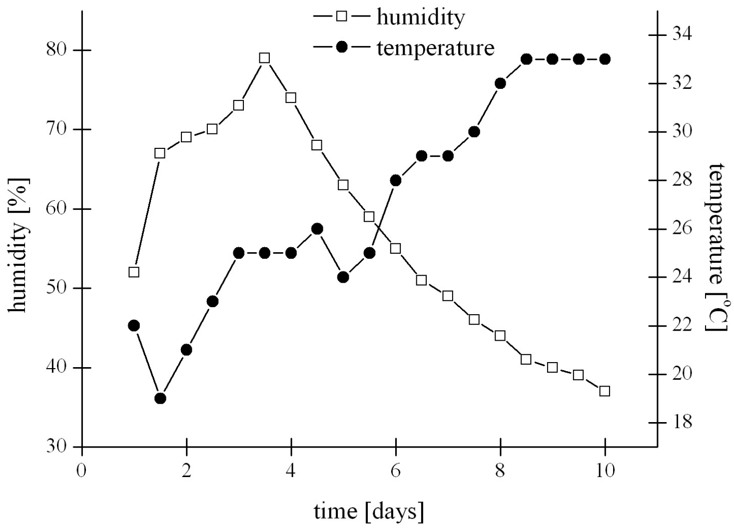

Fig. 6. Temperature and humidity of outlet air in reactor No. 3

Air humidity at the beginning of the composting process was kept on the level of about 52%. The highest value of this parameter reaching 75–79% was obtained after 3 days of the process. At the end of the process, air humidity dropped to the value ranging from 37% to 39%. Initially, the outlet air temperature was 21 °C to 23 °C. The highest value of this parameter – about 33 °C, was obtained on the last days of the process. During the tested processes no high temperatures of the outlet air were found which could be due to temperature of the composting waste.

Table 1 presents the moisture content and dry mass of composting biomass at the beginning and at the end of the typical process carried out in reactor No. 3. At the beginning of the process moisture content was 0.85 $kg_{H_2O}/kg_{wet\ weight.}$ During biodrying process 50% drop of moisture content was obtained.

In the investigations carried out in reactor 3 the highest results of the drop in moisture content of the composted waste and a high temperature were obtained. In the research carried out by ADANI et al. (2002) and SUGNI et al. (2005) high temperatures of 60–70 °C were attained but the inlet air temperature was equal to 40 °C.

What is more, the air was supplied from different directions which made it possible to obtain high temperatures.

In the present study waste of high initial moisture content of 0.80–0.86 $kg_{H_2O}/kg_{wet\ weight}$ was used to carry out the process of autothermal drying. In reactor 3, supplying the air of temperature 30 °C, a 50% drop in moisture content of waste was obtained. An analogous drop in moisture content was attained by ADANI et al. (2002) and SUGNI et al. (2005). Nevertheless, the initial moisture content was smaller by half and it was equal to 410 $g_{H_2O}/kg_{wet\ weight}$, what allowed to obtain low final moisture content of composted waste mass equal to 205 $g_{H_2O}/kg_{wet\ weight}$.

On the other hand, in reactors 1 and 2 a satisfactory drop in moisture content and high values of temperature were not accomplished which could be caused by the low temperature of the air (23 °C) supplied to the reactors and its poor distribution. The results obtained by the Authors and by ADANI et al. (2002) as well as by SUGNI et al. (2005) demonstrated the importance of maintaining the air supply at the appropriate level and a proper temperature to obtain a good end product.

Additionally, in the test cycle carried out in reactor 3 the elementary analysis of composting waste was performed and the heat of combustion and calorific value were determined. Table 2 gives results obtained for a typical process.

Table 2

Biodrying process results in reactor No. 3

Parameter	Content (mean value)
Dry mass [kg dry mass/kg wet weight]	0.53
Organic dry mass [g organic dry mass/g dry mass]	0.716
Ash [g ash/g dry mass]	0.284
Carbon [%]	32.26
Nitrogen [%]	3.19
Hydrogen [%]	4.03
Sulfur [%]	0.31
Oxygen [%]	31.78
Heat of combustion [kJ/g waste]	12.28
Calorific value [kJ/g waste]	10.98

The energy values obtained in the measurements carried out in the calorimeter, i.e. the heat of combustion of 12.28 kJ/g waste and calorific value of 10.98 kJ/g waste, were close to the value (10 531 $kJ/kg_{wet\ weight}$), which was attained by ADANI et al. (2002) and SUGNI et al. (2005).

After the process of autothermal drying, the investigations of pyrolysis and gasification for the dried waste in reactor 3 were carried out (ILMURZYŃSKA and CELIŃSKA 2008). The biomass underwent the process of pyrolysis at the temperature 100–400 °C under an influence of supplied heat producing char, gas and tar.

Main components of a pyrolytic gas are carbon dioxide, carbon monoxide, hydrogen and methane (figure 7).

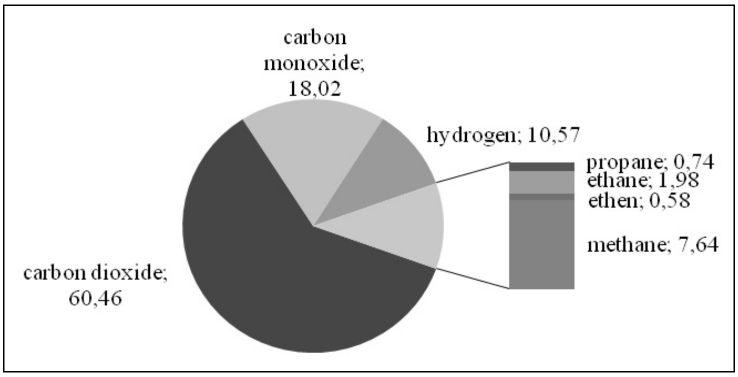

Fig. 7. The composition of gas from pyrolysis of biomass in reactor No. 3

The char obtained as a result of biomass pyrolysis at the temperature 100–400 °C undergoes further pyrolysis at the temperature 400–800 °C with a release of, among others, hydrogen and methane and is subjected to the reaction of allothermic gasification in the presence of carbon dioxide with a release of carbon monoxide mostly (77%) and hydrogen (21%), (figure 8).

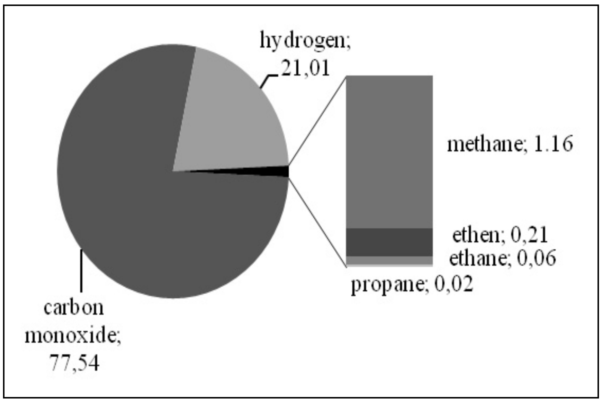

Fig. 8. The composition of gas from gasification of carbonisate in reactor No. 3

The results of pyrolysis and gasification confirmed that dried material constitutes a good biofuel of appropriate energy content.

The obtained values of the heat of combustion, the calorific value and the results of pyrolysis and gasification indicate that wastes dried autothermally may be used as a fuel.

4. CONCLUSIONS

A proper control of autothermal drying process parameters makes it possible to dry composted biomass in a short time.

The process of biological autothermal drying with heat generated during waste composting was carried out in 3 reactors of various construction. It was confirmed that in vertical reactor a high decrease in moisture content and high temperatures were not obtained. On the other hand, in horizontal reactor No. 2, as a result of mixing of biomass, higher values of temperature 40°C were obtained but a satisfactory decrease of moisture of composting waste was not attained. In the experiments carried out in horizontal reactor No. 3 a 50% decrease of water content in the waste was obtained. Moreover, high temperatures of the composting biomass reaching about 53 °C were generated despite the fact that the inlet air temperature was not high – about 30 °C.

In the tested processes in reactor no 3 the dried material of moisture content of about 0.46 kg_{H_2O}/ $kg_{wet\ weight}$ was obtained. Its calorific value and the heat of combustion were 10.98 kJ/g waste and 12.28 kJ/g waste respectively. Dried material of such parameters enabled the production of biofuel. The material obtained in this reactor underwent the process of pyrolysis at high temperature and char obtained was subjected to further pyrolysis at the temperature 400–800 °C, which confirmed that the obtained material may be utilized as biofuel of satisfactory energy content.

Nonetheless, further investigations on the optimisation of the process conditions of biodrying, undertaken in order to obtain storable material of lower moisture content, should be continued.

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