Study of a Composting Process in the Green Waste Processing Plant

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Abstract

Composting of sewage sludge together with green waste such as grass, leaves, branches, etc. is carried out in Poland on many objects. A common problem of all exploiters is the selection of the type of composting technology and its modification to the conditions prevailing in a particular region because the waste, that given objects are exposed to, is different which makes it necessary to adapt the technology to the conditions prevailing in the given facility. In the field of technological research of the composting process, the expected effect of the research was the characteristics of conditions for composting organic waste in relation to the efficiency achieved, indication of the optimal technological parameters and assistance in the selection of the target composting technology. The waste composting technology is based on the appropriate selection of the composition of the prisms and the periodic transfer of the piles by means of a specialized turning machine.

For the purpose of the study project, the following research problem was formulated: what is the intensity of the composting process depending on the technological parameters of the prism (the size of the prism, the types of waste), the properties of the waste, the intensity of aeration by turning?

According to the above basis, the following research hypotheses were identified:

– *the intensity of composting decreases with the increase of the cubic capacity (height) of the prism,*
– *the intensity of composting decreases with the decrease in the frequency of waste transfer,*
– *the intensity of composting decreases as a result of the application of organic waste.*

Keywords: composting, waste, sludge, microorganisms, stabilization, biodegradation

Introduction

The research was carried out in the green waste treatment plant and sewage treatment plant "Boguszowice" owned by BEST – EKO SPÓŁKA Z o.o., located in Rybnik at 101 ul. Rycerska Street. The studies were field-oriented. There is a sludge and composting square within the palnt, with an area of 16250 m², used for the composting process. The composting process begins with laying the right amount of waste on the square with the loader into a prism with a trapezoidal cross-section. The composted waste consists of: green waste (mainly grass and leaves), stabilized sewage sludge and ground shredded branches. After arranging the right amount of waste, the prism is turned, which, in addition to aeration, also allows better homogenization of the material. The freshly laid prism after being turned, and a prism on the last day of intensive composting is shown in photograph 1. Waste prisms can be placed in a hall or external square. The composting process is divided into two phases: intensive composting and compost maturation. Composting time in aerated piles (intensive composting phase) lasts from 15 to 30 days. The prisms are aerated by means of a mobile turning machine. After the intensive composting process, waste from prisms is laid in the so-called monoprism up to a height of 5.5 m (compost maturation phase). The assumed time of compost maturation in prism is 45 days.

During the experiment, the impact of waste mass, frequency of passing, ambient temperature and placement of prism for the tent hall or outside (weather conditions) on the temperature distribution, changes in the process gas concentration and the intensity of the composting process were examined. Six prisms were examined in detail during the experiment. The duration of testing each of the prisms was about 7 weeks.

The materials from which the prism was composed always consisted of grass (green waste), stabilized and drained sludge, and shredded branches. The volume ratio was the same each time and it was 4 parts of green waste, 2 parts of branches and 1 part of sediment.

Measurements of waste characteristics

As part of the research, samples of materials used to form a prisms (grass, sewage, and ground branches), as well as samples from each prisms during the composting process were sampled. The test models were selected in accordance with the guidelines Haug (1993) and Rosso and wsp. (1993). The following analyzes were carried out in the samples taken: humidity, loss on ignition, bulk density, AT_4 breathing activity for Binner et al. (2012).

Measurements of gas emissions

Measurements were provided in field conditions. The tests of the aeration process were carried out using a probe

Photo 1. Composting of waste in prisms, from the left prism after transferring the first day of research, prism on the last day of the intensive composting process, mobile turning machine.
Zdjęcie 1. Kompostowanie odpadów w pryzmatach, z lewej pryzmy po pierwszym dniu badań, pryzma w ostatnim dniu intensywnego kompostowania, mobilna mieszarka

made of acid steel, with holes at the end and a handle at the beginning. The probe included a plastic hose, through which the gas was sucked from the probe to the electrochemical analyzer from Kimo, Kigaz 200, and a thermocouple to measure the temperature of the tip of the probe.

Location of measurement points

Alongside the prism measurements were made at 1/5, 2/5, 3/5, 4/5 lengths on both sides of the prism. Subject to differences in lengths of the prism, the places of measurement were determined each time for each newly created prism. Three measurements at different heights were made on each of the above-mentioned prisms. The measurement heights H were different depending on the size of the prism. The simulation of measurement points for the organic waste composting process was carried out based on the methodology developed by Mason (2005).

Waste characteristics

The sewage sludge in all prisms was characterized by a humidity content exceeding 70%, and showed an ignition loss of approx. 50% d.m.c. Wider differences were observed in the bulk density of sewage sludge, which ranged from 624 kg/m^3 to 889 kg/m^3. Sewage sludge applied to form the prisms revealed AT4 in the range of 20.57 mg O_2/g d.m.c. up to 48,20 m O_2/ g d.m.c.

Another component, grass, similarly as in the case of sewage sludge showed similar humidity values in each of the prisms from 36.18% to 55%. Ignition losses ranged from 47% d.m.c. up to 58.90% d.m.c. There was a variety of bulk density for grass in each prism; the lowest value was obtained was 194 kg/m3, and the highest value was 470 kg/m^3. Significant differences were also noted in the AT_4 grass value – the value was within 50.14 mg O_2/g d.m.c. up to 83.78 mg mg O_2/g d.m.c.

Shredded branches showed humidity between 35% and 50%. Losses on ignition reached values from 53% d.m.c. up to 70.49% d.m.c. The breathing activity of branches in prisms did not differ significantly and amounted on average to approx. 17 mg O_2/g d.m.c. The bulk density of this component varied, ranging from 265 kg/m^3 to 543 kg/m^3.

The sludge was characterized by nitrogen content from 1.9 to 3.07%, carbon from 18.2 to 29.6%, hydrogen from 2.78 to 4.60% and sulfur from 0.727 to 1.230%. The ground branches were characterized by low variability of nitrogen content ranging from 1.17 to 1.78%. The content of carbon and hydrogen decreased over time and amounted to 36% and 3.6%, respectively.

The systematic decrease in the content of these elements resulted from the use of the same material for the formation of prisms. The sulfur content was variable and ranged from 0.152 to 0.247%.

The most variable material in terms of elemental composition was grass (green waste). The nitrogen content varied from 1.04 to 1.69%, carbon from 21.44 to 36.1%, hydrogen from 3.02 to 5.09% and sulfur from 0.152 to 0.244%. The high variability within this group of waste resulted from the variability of the composition associated with the season (spring and summer, a larger share of grass, in the autumn a larger share of leaves and branches).

After mixing in the determined proportions of waste (volumetric grass, branches, sludge 4: 2: 1) waste samples were again collected and the elemental composition determined therein. Samples were also collected after the end of the process (about 50 days of the composting process). The analyzes carried out show that in all tested prisms the elemental composition on day 1 of the process was similar and ranged from 1.66 to 2.20% of total nitrogen, from 24.4 to 30.4% of coal, from 3.06 to 4.00% nitrogen and from 0.281 to 0.460% sulfur. The ratio of carbon to nitrogen ranged from 11.3:1 to 17.5:1, which is below the optimal value for the composting process of 35:1 to 25:1.

The nitrogen content after the composting process in the part of the analyzed prisms decreased compared to the results obtained on the 1st day of the process, and in part of the prisms an increase in the nitrogen content was noted. The carbon content after the process ranged from 19.0 to 32.3%. In the case of carbon content in all heaps, a decrease in the content of this element was noted by several percent. The ratio of carbon to nitrogen decreased in all prisms and ranged from 11.2:1 to 14.8:1. The hydrogen content also decreased slightly in the majority of examined prisms. It ranged from 2.71 to 3.94% in the prism. The sulfur content after the process changed slightly and depending on the prism it was an increase or decrease.

Change of temperatures during the composting process

A significant difference in the temperature of the prisms tested in the summer and autumn-winter season was noticed. The most favorable temperature distribution was shown by the first prism, tested in the summer season on the external square and turned twice a week. After the initial temperature

Tab. 1. Basic technological parametres of prisms
Tab. 1. Podstawowe parametry technologiczne pryzm

Prisms	Creating the prisms	Closing the prism	Number of days of composting	Turning frequency	Prism localization
1	04.07.2017	22.08.2017	50	2 times a week	External
2	25.07.2017	12.09.2017	57	1 per week	External
3	22.08.2017	12.10.2017	52	No turning	Internal
4	20.09.2017	09.11.2017	52	No turning	External
5	19.10.2017	07.12.2017	50	1 per week	External
6	19.10.2017	07.12.2017	50	1 per week	Internal

Tab. 2. The mass composition of the prisms before and after the process
Tab. 2. Skład masowy pryzm przed i po zakończeniu procesu

Prism	Material	Mass of component	Mass percentage	Masa pryzmy	Mass of prism after process	Mass reduction
		kg	% masowy	kg	kg	%
1	Sludge	20220	28,5	70880	24320	65,7
	Grass (green waste)	28720	40,5			
	Shredded branches	21940	31,0			
2	Sludge	19600	23,9	81860	-	-
	Grass (green waste)	48540	59,3			
	Shredded branches	13720	16,8			
3	Sludge	19400	39,1	49580	35420	28,6
	Grass (green waste)	19740	39,8			
	Shredded branches	10440	21,1			
4	Sludge	6680	15,9	42030	39960	4,9
	Grass (green waste)	22550	53,7			
	Shredded branches	12800	30,5			
5	Sludge	6620	17,6	37520	34100	9,1
	Grass (green waste)	21220	56,6			
	Shredded branches	9680	25,8			
6	Sludge	6120	16,6	36960	39710	-7,4
	Grass (green waste)	20920	56,6			
	Shreded branches	9920	26,8			

of about 30°C in the second week of testing, it increased to almost 60°C. Such value lasted until about the 35th day of the process; then it gradually started to drop to around 46°C, to finally increase by a few degrees in the last stage of the research (about 48°C). The high temperature of the prism was also maintained due to the high ambient temperature, reaching an average of 23°C.

The second prism also located on the outside square in the summer differed in the frequency of turning (once a week). There were larger temperature fluctuations (close to 70°C in the third week of testing, which could have a high outside temperature of 36°C). In the initial stage of the process, it was about 65°C, then it gradually decreased by 50°C on day 30 to 40°C at the end of the analysis. It can be noticed that the temperature increases after the material has been turned.

The third prism was characterized by a lower temperature than the previous two prisms, which lasted for the most part at about 45°C. One measurement was recorded deviating from this trend (about 59°C in the second week), followed by a lowering of the outside temperature from approx. 20°C to 14°C. The lower ambient temperature was maintained until the end of the prism measurements, which could affect the temperature of the material. Its relatively constant level can also be explained by the location of the prism in the roofed hall, where it was not exposed to sunlight and the lack of turning.

Prism 4 showed an initial temperature of 43°C; then it rose to about 65°C in the second week of the process, then gradually dropped down to 21°C in the final stage of the research. This decrease can be explained by the non-passing of material and lower ambient temperature (fall season, external square).

The temperature in prisms 5 and 6 was similar: initially, these prisms showed a temperature at 52°C (5) and 60°C (6), which lasted until about the 9th day of the process. Subsequently, these temperatures dropped sharply to around 30°C, so that later, with slight fluctuations caused by material transfer, the level would reach several degrees. The time of year had an impact on it; a sharp drop in temperature after day 9 of the process was probably caused by the lowering of the outside temperature from 13.5°C to 4.5°C.

Tab. 3. Physicochemical characteristics of materials used to compose prisms
Tab. 3. Właściwości fizykochemiczne materiałów użytych do skomponowania pryzm

Prism	Material	Humidity	Losses at ignition		AT$_4$		Bulk density
		(%)	(%d.m.c.)	average	(mg O$_2$/g d.m.c.)	średnia	(kg/m^3)
1/2	Sludge	73,83	49,13	49,57	48,51	48,20	624
			49,62		47,88		
			49,97				
	Grass (green waste)	51,89	47,21	47,73	61,09	65,96	194
			49,58		70,82		
			46,41				
	Shredded branches	35,30	69,30	70,49	15,98	18,34	265
			70,32		20,70		
			71,84				
3	Sludge	63,85	31,83	31,32	22,62	20,57	859
			31,96		18,52		
			30,16				
	Grass (green waste)	36,18	57,65	58,90	52,19	50,14	368
			59,98		48,08		
			59,08				
	Shredded branches	35,91	57,20	56,37	17,96	18,62	469
			57,42		19,27		
			54,49				
4	Sludge	76,24	55,62	53,84	61,68	59,86	757
			53,13		58,03		
			52,77				
	Grass (green waste)	58,89	47,12	46,98	75,18	64,61	470
			46,53		54,03		
			47,27				
	Shredded branched	56,52	54,12	53,43	25,19	33,80	543
			53,03		42,42		
			53,15				
5/6	Sludge	77,83	11,85	52,07	39,95	39,89	889
			12,27		39,83		
			11,51				
	Grass (green waste)	56,26	71,42	71,25	86,16	83,78	278
			70,83		81,39		
			71,49				
	Shredded branches	52,05	23,35	53,82	13,21	14,94	442
			24,12		16,68		
			23,32				

Changes in gas concentrations in compost prisms

Concentration of O$_2$

The biggest fluctuations can be observed in the case of prisms flipped in the summer season. In both of them, the oxygen level decreased until the moment of turning, after which it increased and dropped again until the next transfer. The lowest value of oxygen concentration for prism 1 was recorded in the fifth week of testing (about 7%), in the case of the second prism and in the 3rd week (6%). A relatively constant level of oxygen concentration close to 20% was observed in the 3 (non-turned) prism, which, however, did not translate into the results obtained for the second of the non-turned prisms. Prisms 5 and 6, despite turning once a week, did not show significant changes in O$_2$ concentration (about 19%).

Concentration of CO

Increased its concentration was observed only in prisms 1 and 2, the next ones did not show a significant share of CO. For the pile 1, the maximum concentration was about 110 ppm at the beginning of the process, in the case of 2 – about 82 ppm in the 3rd week of testing.

Concentration of CO$_2$

Similarly to the previous parameter, also here the largest fluctuations were in the case of prisms 1 and 2, the increase in CO$_2$ concentration occurred in the prisms 2 immediately after the changeover. The maximum concentration for both prisms was approx. 13%. The minimum values were reached in the 6th week of the process in the prism 1 (1% CO$_2$) and in the 5th week for the prism 2 (0.5% CO$_2$). The lowest level of carbon dioxide concentration was recorded in case of prism 3. Initially it was 6%, then it dropped and remained relatively constant (about 1%) except on the 35th day of the process, when this concentration increased to about 3%. Prism 4 showed two points of increase in CO$_2$ concentration: 8% in the first week of the process and 6% in the 4th week. At the final stage of the research, it was characterized by a carbon dioxide concentration of approx. 3%. There was an initial increase in the concentration of carbon dioxide in the heaps of 5 (5%) and 6 (8%). Both of them had a relatively constant and similar level of carbon dioxide concentration (about 2%).

Concentration of NO

In prism 1 after the initial NO concentration at the level of approx. 22 ppm, its decrease was noted to the value close to 1 ppm, which was maintained with slight fluctuations during most of the process duration, to finally reach the level of approx. 4 ppm. The largest fluctuations of this parameter were observed in the case of the second and third prisms. Both of them were characterized by an initial low concentration of NO (about 1 ppm), which increased in the final stages of the process. In the case of prism 2, the highest value was recorded on the 43th day of the process and it amounted to approx. 22 ppm, while for the prism 3 it was 33 ppm on day 35. However, the final concentration in prism 2 was lower and amounted to approx. 1 ppm, while in prism 3 it was 22 ppm. Prism 4 was characterized by an NO concentration of approx. 5 ppm (except for a significant decrease to 0 ppm in the 3rd week of the process and an increase to 10 ppm on day 29 of the study). Prisms 5 and 6 showed a similar course of nitric oxide concentration in the material. After forming the prisms, it was about 9 ppm, then the concentration dropped to about 1 ppm, which persisted until the end of the process.

Changes in the physicochemical composition of compost prisms

In each of the analyzed cases, a decrease in the organic matter content was observed, whereas for the first prism 3 it showed the smallest fluctuations ($R^2 = 0.96$). The largest decrease in the organic matter content was demonstrated by the prism 2 and transferred once a week, and located in the summer on the external square. A similar level of removal of organic compounds was recorded in the case of prisms 1 and 3, however the first one was characterized by the determination coefficient $R^2 = 0.68$. Prisms 5 and 6 showed the smallest decrease in the content of organic compounds, which was affected by the low outdoor temperature and high humidity in the hall close to 100%. The high biodegradability of composted wastes was noticed, similarly to Tita et al. (2007).

The content of organic matter in prism 1 is represented by losses on ignition. On the first day it was 54.66% d.m.c., then gradually the value deceased to 38.33% d.m.c. Material moisture in the prism decreased from almost 60% to 22.53%, which could be affected not only by frequent shifting (twice a week), but also by the season (sunshine in the summer on the outdoor square), a similar trend was noticed by Smith and Eliers (1980). The initial weight was 436 kg/m³, then it increased reaching the highest value of the 29th day of measurements (629 kg/m³) to reach the final value of 478 kg/m³. When forming the prism 1, the material exhibited breathing activity equal to 55.21 mg O_2/g d.m.c., and during the process the index decreased to 1.47 mgO_2/g d.m.c. on the 50th day of measurements. A significant drop occurred between 3 and 4 weeks of composting (from 37.03 mg O_2/g d.m.c. to 5.17 mg O_2/g d.m.c.).

Prism 2 showed a greater level of organic compound decline than prism 1. Initially, the loss on ignition was 61.44% d.m.c., dropping to a final value of 38.56% d.m.c. Humidity of the material was characterized by high variability. On the 1st day of the measurements it was 55.49%, then during the process it decreased even to about 25% (43 measurements), so that in the final stage it would increase again to 35.58%. The bulk density of the material in prism 2 increased steadily from an initial value of 252 kg/m³ to 592 kg/m³ on the 57th day of measurements. Respiratory activity of the prism 2 decreased from 63.03 mg O_2/g d.m.c. on day 1 of measurements to 3.08 mg O_2/g d.m.c. on day 57. The highest decrease was recorded between 2 and 3 weeks of the process (from more than 50 mg O_2/g d.m.c. to half the value – 24.06 mg O_2/g d.m.c.) and between 3 and 4 weeks (from 24.06 mg O_2/g d.m.c. to 6 62 mg/g d.m.c.).

For the prism 3, a steady decline in losses on ignition from 56.56% d.m.c. up to 40% d.m.c. Material humidity decreased from 58.79% on the first day of the process to 37.66 on day 36, and then increased to 47.35%, so that on day 52 it decreased to 43.08% again. The bulk weight at the beginning of the process was 436 kg/m³, then it gradually increased to the 15th day of measurements, recorded a drop in 22 days (459 kg/m³) to get a maximum one week later (629 kg/m³). The final value of the bulk density was at the level of 478 kg/m³.

The breathing activity of the material on day 1 of measurements was over 40 mg O_2/g d.m.c. It decreased to day 22 of measurements to increase again on day 30 (20.54 mg O_2/g d.m.c.). One week later, it rapidly decreased to about 5 mg O_2/g d.m.c. and remained at this level until the end of the process.

Significant decrease in the organic matter content between the 1st and 7th day of measurements was observed for the prism (loss of roasting decreased from 70.25% d.m.c. to 50.85% d.m.c.). Then the material showed a gentle decrease in the value of this parameter, up to the final value close to 38% d.m.c. Humidity of the material varied depending on the amount of atmospheric precipitation (the prism was on the external square) – the highest value of humidity obtained on day 1 with rainfall 104 mm (69.88%), then fluctuated and at the end of the process was over 68%. The bulk load at the beginning of the process was 558 kg/m³, then with variations on the 7th and 37th day of measurements, it increased up to 694 kg/m³ in the penultimate test week, to reach the level of 579 kg/m³ in the final stage of measurements. Respiratory activity of the material at the beginning of the 4 prism test was almost 50 mg O_2/g d.m.c., then gradually decreased to 7.13 mg O_2/g d.m.c. at 37 days of analysis, to increase again to over 15 mg O_2/g d.m.c. on day 42 and almost 10 mg O_2/g d.m.c. (last measurement, 51 days). The difference between the last two values can be caused by rainfall to which the material was exposed.

For the prism no. 5, the material losses during the entire test period decreased from 58.59% d.m.c. up to 45.77% d.m.c. Humidity of the material was maintained at a high level, starting from almost 62% on the first day of measurements, through approx. 68% in the middle of the composting process (22, 29 days), ending with 63.7% on the 50th day of testing. Although the prism was not located on an external square, it was created in the autumn season, when the outside temperatures were low. The bulk density of the prism 5 has changed from an initial value of 410 kg/m³ to as high as 659 kg/m³, and in the last stage of the measurements it has reached the level of 642 kg/m³. Breathing activity up to the 22 day of measurements was maintained at a level exceeding 20 mg O_2/g d.m.c., and then gradually decreased to a dozen or so mg O_2/g d.m.c. (about 13 mg O_2/g d.m.c. on day 42 of the study).

For the prism no.6, there was a similar level of loss of loss on ignition as in the previous prisms. Both of them were at the same time in a roofed hall, so as in the case of pile 5, the moisture content of the material did not decrease. In the initial stage of the research, 53.17% of humidity was recorded, and on the last day of measurements it was over 60%. The bulk weight of the prism 6 varied in a similar way to the bulk density of the prism 5 – its growth was observed from 375 kg/m³ (1 day) through 715 kg/m³ in the penultimate week to 642 kg/m³ in the final stage of the analyzes. The AT_4 values of prisms 6 shaped analogically to the value of this index for prism no. 5, however, they achieved a lower final value (8.33 mg O_2/g d.m.c.).

Summary of the research

The research revealed that the oxygen conditions in the prisms were positive regardless of the technological regime applied. The low intensity of turning, placement of prisms in the hall and relatively low outside temperatures (at a high ratio of area to volume of prisms) caused cooling of the prisms and low efficiency of water removal. In the prisms where the temperature was above 50°C for several weeks, a high dynamics of the decrease in breathing activity was observed, as a result of the deepening stabilization of organic matter. Temperatures obtained in the study may not be sufficient to achieve complete hygienization of compost and weed seed inhibition. It was found that the necessary technological activity is to carry out the turning of waste in prisms with an average frequency at least once a week. A higher frequency is not required unless an oxygen deficit is found in the prisms (concentration <7%). The mixture of waste components should be prepared in such a way that the final initial humidity is in the range from 50 to 60%. The size of the prism should be designed so that the surface to volume ratio does not exceed 2.5. In autumn and early spring, at low ambient temperatures, in order to maintain good thermal conditions in the heap, the piles should be constructed in a way that allows the surface to volume ratio to be below 2.

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Badania procesu kompostowania w zakładzie przetwarzania odpadów zielonych

Kompostowanie osadów ściekowych wraz z odpadami zielonymi takimi jak trawa, liście, gałęzie itp., prowadzona jest w Polsce na wielu obiektach. Wspólnym problemem wszystkich eksploatatorów jest wybór rodzaju technologii kompostowania oraz jej modyfikacja do warunków panujących w danym regionie, ponieważ odpady trafiające na poszczególne obiekty różnią się od siebie, co powoduje konieczność dopasowania technologii do warunków panujących na danym obiekcie. W zakresie badań technologicznych procesu kompostowania spodziewanym efektem badań była charakterystyka warunków prowadzenia kompostowania odpadów organicznych w relacji do uzyskiwanych efektywności, wskazanie optymalnych parametrów technologicznych oraz pomoc w doborze docelowej technologii kompostowania. Technologia kompostowania odpadów oparta jest na odpowiednim doborze składu pryzm oraz okresowym przerzucaniu pryzm za pomocą specjalistycznej przerzucarki.

Na potrzeby projektu badań sformułowano następujący problem badawczy: jaka jest intensywność procesu kompostowania w zależności od parametrów technologicznych pryzmy (wielkość pryzmy, rodzaje odpadów), właściwości odpadów, intensywności napowietrzania poprzez przerzucanie?

Na tej podstawie zidentyfikowano następujące hipotezy badawcze:

– *intensywność kompostowania maleje wraz ze wzrostem kubatury (wysokości) pryzmy,*
– *intensywność kompostowania maleje wraz ze spadkiem częstotliwości przerzucania odpadów,*
– *intensywność kompostowania maleje w wyniku stosowania zagnitych odpadów organicznych.*

Słowa kluczowe: kompostowanie, odpad, osad, mikroorganizmy, stabilizacja, biodegradowalność