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CO – COMPOSTING OF MEAT PACKING WASTEWATER SLUDGE AND ORGANIC FRACTION OF MUNICIPAL SOLID WASTE

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ABSTRACT

The use of organic manures as amendments to improve soil organic matter level and long term soil fertility and productivity is gaining importance. The disposal of the great quantity of organic wastes produced by the municipal, agricultural and agroindustrial activities, is causing energetic, economic and environmental problems. Sludge composting and using them in agriculture should be a priority for their disposal. Sludge should be treated not as a waste but as a valuable non-farm sources of organic matter to soil. The composting process is a useful method of producing a stabilized material that can be used as a source of nutrients and soil conditioner in fields. The objective of this study was estimation of optimal dose of sewage sludge in composting mixture to obtain of mature and stable compost. The mixture was prepared from sewage sludge (10-40%), organic fraction of MSW(30%), grass (20-50%), sawdust as a bulking agents. Maximum temperature in the bioreactor reached 68.9°C between 1st and 3rd day of composting, and the mean temperature during this period fluctuated from 36 to 46°C. Later, the temperature gradually decreased and after 30 days of composting it approached ambient air temperature which means the end of process. There was significant impact of the high temperature on the rate of the process and of the extent of the hygienisation. The results show that all initial samples are infected with helminth eggs but there is a large variation in the degree of infection for the different sludge samples (102 to 256 eggs kg^{-1} d.m.). The inactivation of the helminth eggs in the compost can be accomplished, if the temperature inside of the reactor is sufficient as in the case M III and M IV. The final compost M III and M IV was well sanitized as a result of the high temperature achieved due to higher grass addition in those mixtures. Composts M I and M II can not be used in agriculture because of bad microbiological characteristic, however MII can be used for recultivation after hygienisation. The composted material assumed the appearance and structure similar to the so-called horticultural soil. As an exothermic process, composting caused very high loss of water in composted material. All the composts were granular, dark grey in color without foul odor and attained an ambient temperature after 30 days of composting, indicating the stable nature of composts. Additional researches are required in order to optimize the better organic and nitrogen compounds degradation during co-composting process.

KEYWORDS: co-composting, sewage sludge, organic fraction of MSW.

1. INTRODUCTION

The meat industry in Poland is currently made up of about 3,500 businesses but in comparison with the countries of Western Europe is highly fragmented. Operating in the country of the industry vary to size (from large conglomerates of producing more than 10 000 Mg $year^{-1}$ for small family companies) as well as the activity profile (slaughterhouses from processing and slaughterhouses only) (Bartkiewicz, 2007; Konieczny and Uchman, 1997; Olszewski, 2002). Meat industry plants is seen as a place that are difficult to purify industrial wastewater with high organic load, nutrients and high concentration slurry and inorganic salts. This leads to the formation of sludge of a similar nature. The presence of phosphorus in the sludges is due to its content in the feces of animals. Another of his sources are detergents used for washing equipment and work surfaces. These sludges are also dangerous in terms of epidemiology, because they contain pathogenic microorganisms from such the digestive systems of animals for slaughter (Konieczny *et al*., 2007). Sewage sludge, also referred as biosolids, is major byproduct of sewage treatment process typically containing 0.5-15% total solids (TS). Most of them are organic compounds, with the broad range of volatile solids content (50-80%) commonly 75% to 80% (Poon and Boost, 1996) Sludge production and characteristics are highly depended on the wastewater composition and the treatment technology used. The mass of sewage sludge produced in the European Union has increased from 5.5 million tons (dray matter) in 1992 to 10.2 million tons in 2009, and 39% of these biosolids are currently recycled to agricultural land (European Commission Report, 2010). Land application of sewage sludge has a great incentive in view of its fertilizer and soil amendment, unless it contains toxic compounds. The heterogeneous nature of biosolids produced in different wastewater treatment plants necessitates knowledge of the chemical and biological properties of sewage sludge prior to the land application (Sikorski and Bauman-Kaszubska*,* 2008). Although the meat-packing wastewater sludge (as well as other food industries) does not contain toxic substances, it does include enormous amounts of organic substances which can be succesfully composted (Mizgajski and Andrzejewska-Wierzbicka, 2003). Sludge composting and using them in agriculture should be a priority for their development. The criterions for potential use in favor of natural soil formation are properties of fertilizer. The advantage of the structure of the sludge is that after a few days of storage varies with whipped in a free-flowing and crumbly and convenient for distribution in the soil. Meat-Packing sewage sludge is devoid of odor (Konieczny *et al*. 2007, Tomczak-Wandzel *et al*., 2004). Composting is a biological process, which decomposes and stabilizes organic substances under thermophilic conditions as a result of biologically produced heat (Barrington *et al.*, 2003; Iyengar and Bhave, 2006). The process has been traditionally used as a treatment method for the organic fraction of municipal solid waste (OMSW), agricultural and farming residual sludge from wastewaters treatment plant. The main factors that must be considered in case of biosolids composting are the moisture, pH, the initial C:N ratio, the air supply and porosity of the waste. However, the waste physical/chemical properties may not always be suitable for composting. In many cases, some preliminary changes need to be made to the initial waste. One of the most useful methods is the addition of a bulking material in order to increase the porosity of the waste. Another option is co-composting of two or more types of organic wastes which could include some benefits to the composting process, higher porosity, better C:N ratio, addition of active biomass, or simultaneous management of interesting wastes (Kumar *et al*., 2010). Co-composting of sewage sludge and organic fraction of municipal solid waste seems to be promising method. More than 256,000,000 tonnes year^{-1} of municipal solid waste were generated in the EU in 2009 (Eurostat, 2011). The organic fraction represents approximately 40% (wet weight) of the total amount of MSW depending on the season and waste management system. However, additional studies are necessary to improve the knowledge of the sewage sludge composting process, the most suitable types of waste and bulking agent and its application ratio. The aim of this work was to evaluate and compare the effectiveness of the composting process with different composition of organic waste mixtures and bulking agents.

2. MATERIALS AND METHODS

2.1. Collection and characterization of raw materials

The raw material for co-composting was a mixture of biosolids, organic fraction of MSW (OFMSW), and grass and sawdust as bulking agents. Dewatered biosolids was obtained from meat-processing factory (Poland, Silesian Region). The municipal solid waste was supplied by Municipal Landfill (Poland, Silesian Region) and it was manually sorted into biodegradable and non-biodegradable parts. Chemical characterization of the composting materials is given in Table 1. The compositions of mixtures of composting materials prepared at four different ratios are given in Table 2.

2.2. Reactor

The composting process was conducted in insulated closed batch reactor with the volume of 45 L (Figure 1). For insulation purpose, 5-cm-thick layers of glass wool were used by wrapping the sides of the reactor. The experimental work was conducted at room temperature. Atmospheric air was pumped into the reactor using a valve and a rotameter to control the airflow. The exhaust gas was cooled down to ambient temperature by passing through a condensation arrangement. The air outlet was analysed via gas analyser GA2000 analyzer (Geotechnical Instruments, UK), which enabled the measurements of O_2, CO_2 and NH_3 emission.

Table 1. Chemical characterization of co-composting materials

Parameter	OFMSW	meat-packing wastewater sludge	Grass	Sawdust
Moisture content [%]	41.83 ± 0.4	85.4 ± 4.2	75 ± 1.4	8.92 ± 0.35
Dry matter [%]	58.17 ± 1.45	14.6 ± 0.7	25 ± 1.3	91.08 ± 0.46
Organic matter [%]	85.80 ± 1.6	80.2 ± 7.3	78.7 ± 3.7	87.23 ± 6.8
pH	7.34 ± 0.3	6.8 ± 0.1	7.56 ± 0.4	5.27 ± 0.07
C [% d.m.]	25 ± 1.1	37 ± 2.1	45.9 ± 3.1	46.5 ± 2.78
Kjeldahl N [% d.m.]	1.3 ± 0,1	5.81 ± 0.3	1.1 ± 0.45	0.08 ± 0.00
P [% d.m.]	0.8 ± 0,2	2.8 ± 0.7	3.9 ± 0.2	<0.02
C/N ratio	19.23 ± 0.98	6.36 ± 0.06	41.7 ± 0.65	581.25 ± 5.15
C/P ratio	31.25 ± 1.24	13.21 ± 1.1	11.7 ± 0.3	-

Table 2. Mixing ratios of materials packed in the reactor (w/w %)

Mixtures	OFMSW	meat-packing wastewater sludge	Grass	Sawdust
M1	30	40	20	10
M2	30	30	30	10
M3	30	20	40	10
M4	30	10	50	10

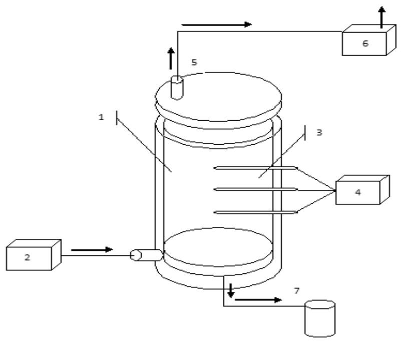

Figure 1. Schematic diagram of the composting bioreactor for the lab scale experiment
1 – insulated reactor, 2 – aeration pump, 3 - temperature sensors, 4 – temperature control system, 5 – gas removal system, 6 – gas analyzer, 7 – leachate removal system

2.3. Analytical methods

The pH was measured potentiometrically in the supernatant suspension of a 1:10 compost:water mixture. For moisture content determination, a given samples was weighted into a crucible and put into an oven heated at a temperature of 105°C over night and reweighted. The difference in weight was expressed at the amount of water in the sample and was used to determine the moisture fraction of the material. The oven-dried sample was further heated at 550°C for 4 h for the determination of volatile solids (VS). Organic carbon in each sample was measured using TOC analyzer (Analytik Jena Multi N/C 2100). Total soluble N was extracted by the Kjeldahl digestion method using Büchi Distilation Unit K-335 equipment, followed by distillation and determination of NH_4-N using titrimetric procedures. Total P was extracted by ammonium vanadate-molybdate method and concentration in the sample was read on spectrophotometer at 470 nm (Hermanowicz *et al.,* 2010).

All compost digestates were analysed for the total content of heavy metals by ICP-Mass Spectrometry (Optima 200 DV), after digesting the samples with a mixture of conc. HNO_3 and HCl (1:3 v/v) in a microwave digester.

The population sizes of E. coli and Salmonella spp. were determined on selective media specific for each microbial group (Hermanowicz *et al.*, 2010). The number of Helminth eggs was determined following Schwartzbrod (2003). Data collected were analysed using Statistical Analyses Systems software. Results have been presented in averages and standard deviation.

3. RESULTS AND DISCUSION

3.1. Changes of temperature

Three typical phases of composting were observed during the process (Figure 2) for all mixtures: (i) a short initial mesophilic phase lasting approximately 2 day; (ii) a thermophilic phase during which the temperature increased, 3 days for M2, four days for M3, 5 days for M1 and M4. During this phase M1 reached maximum temperature of 57,3ºC at 5 days and M2 temperature of 62,5ºC at 3 days of composting. At the same time M3 and M4 reached 68,9ºC at 4 days of the experiment; and (iii) maturation phase, when the temperature decreased slowly to mesophilic values above 40ºC in the mixtures.

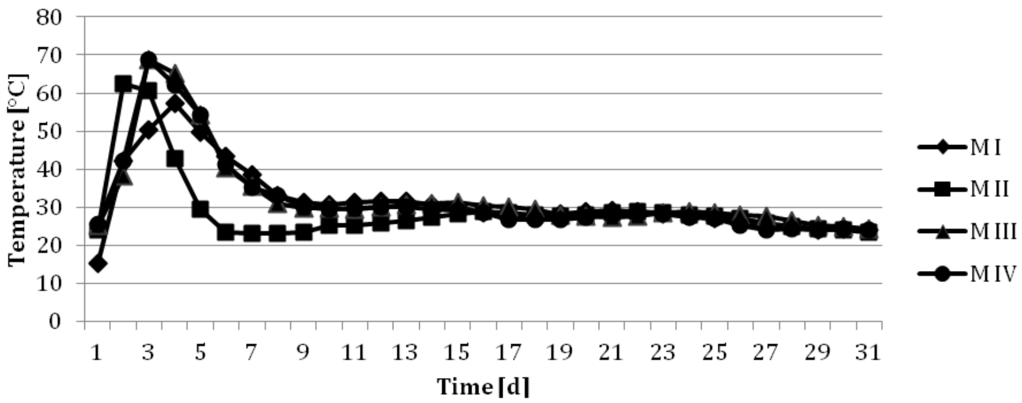

Figure 2. Temperature development during the composting process

The termophilic phase for M1 and M5 were longer (5 days) than recorded for M2 and M3 mixtures. It is well documented, that duration of the thermophilic phase depends on the chemical composition and adjustment of the parameters used to the optimal values (Haug, 1993). At the end of our experiment, after 31 days of composting, the temperature maintained at 24ºC in all the mixtures.

3.2. Changes of CO_2 and O_2

Besides temperature, carbon dioxide production and oxygen consumption are very useful parameters for monitoring of composting process (Henon *et al.*, 2009). The temperature must be positively correlated with CO_2 production and negatively with O_2. The negative correlation between O_2 and CO_2 has been observed for all the mixtures. Oxygen concentration in the exhaust should be maintained between 10% and 18% (v/v) to optimize biological composting (Figure 3) (Magalhaes *et al.*, 1993). The period in which the consumption of oxygen decreased and then increased was corresponding to the period in which the temperature was high and the termophilic condition were observed, which are consistent with the results obtained by Yamada and Kawase (2006).

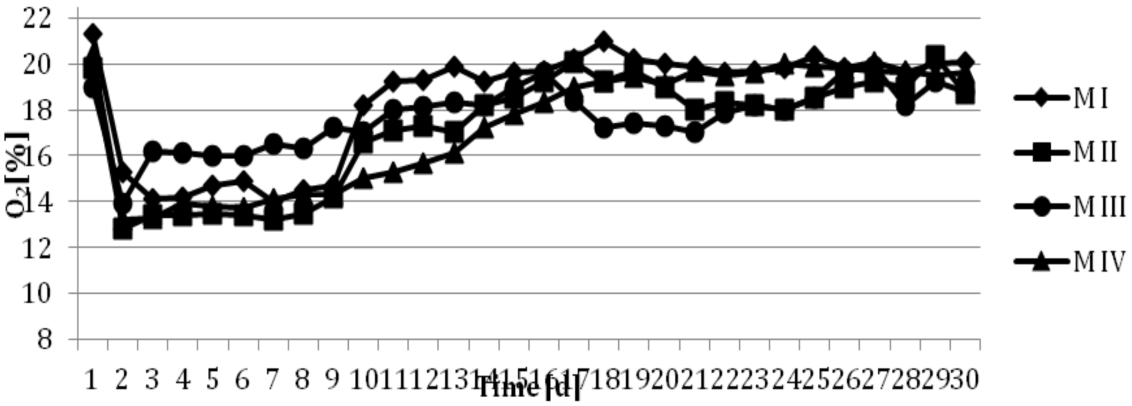

Figure 3. O_2 evaluation of waste mixtures composting

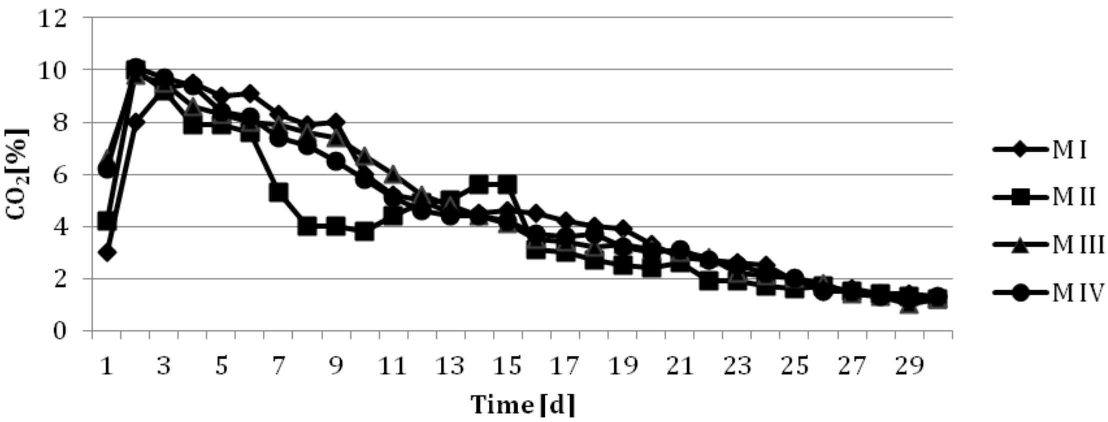

Figure 4. CO_2 evaluation of waste mixtures composting

CO_2 concentration for the all mixtures showed a similar behaviour with temperature variations (Figure 4). During the process, the maximum CO_2 production was note within first a few days of incubation, probably due to easily biodegradable substrate. This phenomenon was strongly observed during composting of mixture IV, where the 50% of mixture was grass. CO_2 concentration gradually decreased in all reactors and it became fairly constant after 27 days.

3.3. Effect of waste mixing ratios on co-compost quality

The moisture content affects the microbial activity directly, the compost temperature, and hence the rate of decomposition. The optimal moisture content for composing at high C/N ratio around 55-60% **(**Vlyssides and Barampouti, 2010). At the beginning of the composting process the moisture content was about 65% for M1 and M2, while for mixtures M3 and M4 was higher 69% and 68% respectively. The moisture content decreased continuously to the end of observation period.

Maintained the pH values within recommended pH range of 3-11 for composting substrates (De Bertolidi *et a.l,* 1983). The final pH values obtained in this study decreased to the neutral values in the range of 7.1-7.5.

The C/N of all mixtures decreased during the composting process although it did not reach low enough values. The C/N ratio was used by many authors as a one of the most important indicators of compost maturity. However, it cannot be used as an absolute indicator of compost maturity due to its large variation depended on composted materials (Kone *et al*., 2009). Fuchs *et al.* (2001) recommended a C/N ratio below 16 for the use of compost. However, Wong *et al.* (2001) found a value around or below 20 satisfactory. The obtained C/N ratio in this study was much higher than recommended by another authors.

The initial values of N-Kjeldahl were on the same level for the all mixtures and there were no observed N losses in the end of composting process probably due to high C/N ratio. The N-Kieldahl concentration in the composting mass remained constant during composting or even increased in all composts by the end of the process. The increase measured in all of the samples was due to loss of weight in the mass being composted as a result of organic matter degradation (Huang *et al*., 2004; Banegas *et al*., 2007; Vlyssides and Barampouti, 2010). Normally, higher N losses have taken place in the mixtures, which had a lower initial C/N ratio. Increase of P content was observed at the end of composting, it could be due to a decrease in organic matter (Haug, 1993).

Table 3. Initial material mixture and co-compost quality for various options tested

Parameter	M I		M II		M III		M IV	
	Initial	Final	Initial	Final	Initial	Final	Initial	Final
Moisture content [%]	64.7 ± 1,2	45.9 ± 1.4	66.6 ± 1.0	47.2 ± 1.0	69.2 ± 1.5	50.3 ± 1.3	68.0 ± 1.7	49.8 ± 1.3
Dry matter [%]	35.3 ± 2.0	54.1 ± 3.6	33.4 ± 2.1	52.8 ± 1.7	30.8 ± 1.1	49.7 ± 1.9	32.0 ± 2.2	50.2 ± 3.2
Organic matter [%]	75.9 ± 2.0	54.3 ± 2.3	80.3 ± 3.1	63.1 ± 2.3	77.8 ± 3.1	52.1 ± 2.9	84.4 ± 3.6	64.3 ± 2.7
pH	6.7 ± 0.0	7.2 ± 0.1	6.9 ± 0.0	7.5 ± 0.1	6.5 ± 0.0	7.1 ± 0.1	6.7 ± 0.1	7.1 ± 0.0
C [% d.m.]	30.7 ± 0.6	26.2 ± 0.8	35.2 ± 0.7	27.7 ± 0.6	33.3 ± 0.9	29.9 ± 0.9	35.3 ± 1.0	30.7 ± 0.8
Kjeldahl N [% d.m.]	1.0 ± 0.7	1.1 ± 0.6	0.9 ± 0.3	1.2 ± 0.0	1.0 ± 0.2	1.4 ± 0.1	0.9 ± 0.3	1.2 ± 0.5
P [% d.m.]	3.7 ± 0.2	4.1 ± 0.0	2.8 ± 0.1	3.9 ± 0.0	2.1 ± 0.2	3.04 ± 0.0	1.8 ± 0.1	2.2 ± 0.0
C/N ratio	30.7 ± 0.1	23.8 ± 0.8	39.1 ± 0.9	23.1 ± 0.9	33.3 ± 1.4	21.35 ± 0.8	39.2 ± 0.7	25.5 ± 0.5

Table 4. The heavy metals concentration in the final compost

Metal	Limits imposed by Polish regulations (Dz.U.2008, No.119, poz.765)	M I	M II	M III	M IV
		Final	Final	Final	Final
Cr [mg kg^{-1} d.m.]	100	116.7 ± 12.3	95.0 ± 8.4	31.7 ± 2.45	18.3 ± 0.32
Cd [mg kg^{-1} d.m.]	5	2.3 ± 0.12	2.8 ± 0.21	4.0 ± 0.12	1.7 ± 0.1
Ni [mg kg^{-1} d.m.]	60	26.7 ± 1.9	31.7 ± 2.34	18.3 ± 1.2	10.0 ± 0.23
Pb [mg kg^{-1} d.m.]	140	145.0 ± 10.1	126.7 ± 9.87	36.7 ± 2.4	20.0 ± 1.7
Hg [mg kg^{-1} d.m.]	2	0.30 ± 0.00	0.20 ± 0.00	0.10 ± 0.00	0.10 ± 0.00

The heavy metal concentration in the final compost product deserves consideration since they may enter the food chain when the digested products are applied on land. The final metal concentration can be compared with the maximum recommended values in the Polish regulations (Dz.U.2008, No.119, poz.765) also shown in table 4. According to these limits the metal concentrations were above the maximum permissible level for organic farming in the mixtures M1 and M2 (with high participation of sewage sludge in composting mixture). The heavy metals were concentrated during composting process due to weight loss in the course of composting following organic matter decomposition, release of CO_2 and water and mineralization process (Zorpas *et al*., 2000; Singh and Kalamdhad*,* 2012).

One of the problems posed by the direct use of composted meat-packing wastewater sludge and organic fraction of municipal solid waste in agriculture is the risk of plant and human contamination by pathogens. During the composting process, coliform, *Salmonella* and number of live helminth eggs were determined in samples taken at the initial and final stage of composting process (Table

5). Literature data showed that helminth eggs could survive with such moisture content in biosolids stored in the environment (Kone *et al*., 2007; Bien *et al.,* 2010; Gallizzi, 2003). The results of that research show that the inactivation of all eggs is possible when the temperature of the compost heaps exceeds 45°C for at least 5 days. Kone *et al*. (2007) observed excellent removal efficiency of *Ascaris* eggs in their study, which can be attributed to the good temperature pattern. They composted fecal sludge mixed with organic wastes; the viability of *Ascaris* eggs was reduced from 58% to less than 20% and 10% within 40 and 60 days, respectively. *Salmonella* is considered as the most specific and problematic microorganism from a hygienic point of view; since it is a universal bacterium with a high grow capacity. Although the presence of *Salmonella* was detected in the initial M I and M II samples, where the content of meat-packing wastewater sludge was the highest, it was not detected in the final samples of all experiments.

E. Coli is the most representative microorganism. Most coliforms died when they are exposed to a temperature of 55ºC for 1h or 60ºC for 15-20 min. The concentration of these pathogens was considerably reduced during the composting process. In all mixtures the obtained temperature and the period of time this temperature is maintained seems enough to reduce this pathogen in the resulting composts.

The results shows that all initial samples are infected with helminth eggs but there is a large variation in the degree of infection for the different sludge samples (102 to 256 eggs kg^{-1} d.m.). The inactivation of the helminth eggs in the compost can be accomplished, if the temperature inside of the reactor is sufficient as in the case M III and M IV. Polish regulations allow the use of composts in agriculture with no presence of *Salmonella* and live helminth eggs.

Table 5. Pathogen density at the beginning and the end of the composting process

Parameter	Limits imposed by Polish reg.	M I		M II		M III		M IV	
		Initial	**Final**	**Initial**	**Final**	**Initial**	**Final**	**Initial**	**Final**
Coliform count	-	10^{-1}	10^{-2}	10^{-4}	not detected	10^{-4}	not detected	10^{-3}	not detected
Salmonella s.p.	not detected	detected	not detected	detected	not detected	detected	not detected	detected	not detected
Helminth eggs [number of eggs kg^{-1} d.m.]	0	154	102	256	167	200	not detected	137	not detected

4. CONCLUSIONS

The use of meat-packing wastewater sludge generated in the wastewater treatment plant of a meat industry and OFMSW as co-substrates are considered to be an interesting option for treating complex organic wastes. It can be concluded that chemical, physical and microbiological parameters provide valuable information on the nature of initial mixtures and obtained composts, and those co-substrates can be successfully composted. Composting of biowastes in the reactor is feasible over a short period with easy control of the most important variables. Decrease in the C / N ratios indicates that the composting process ran correctly however it did not reach low enough values. There was significant impact of the high temperature on the rate of the process and of the extent of the hygienisation. The final compost M III and M IV was well sanitized as a result of the high temperature achieved due to higher grass addition in those mixtures. Composts M I and M II can not be used in agriculture because of bad microbiological characteristic however MII can be used for recultivation after hygienisation.

Additional work is required in order to optimize the better organic and nitrogen compounds degradation during co-composting process.

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