ARCHIVES OF ENVIRONMENTAL PROTECTION
ARCHIWUM OCHRONY ŚRODOWISKA
vol. 31 no. 1 pp. 71 - 82 2005

PL ISSN 0324-8461

RESEARCH ON AEROBIC COMPOSTING OF MUNICIPAL WASTE WITH A VIEW TO HEAT RECUPERATION

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Keywords: composting process of municipal waste, heat recuperation, temperature of compost.

BADANIA DOTYCZĄCE TLENOWEGO KOMPOSTOWANIA ODPADÓW KOMUNALNYCH W ASPEKCIE ODZYSKIWANIA CIEPŁA

Celem pracy było określenie, czy proces kompostowania odpadów komunalnych może być niskotemperaturowym źródłem ciepła. Okreslono, że w trakcie wysokotemperaturowej fazy procesu powstaje średnio 930,5 kJ/kg kompostu. W zaprojektowanym i wykonanym modelu laboratoryjnym przeprowadzono trzy etapy badań, polegające na prowadzeniu procesu kompostowania z jednoczesnym odzyskiwaniem ciepła z procesu. Na podstawie badań określono parametry mające wpływ na efektywność procesu odzyskiwania ciepła; a mianowicie: optymalna początkowa temperatura wody chłodzącej powinna wynosić około 30°C, obniżanie strumienia przepływu wody chłodzącej wpływa korzystnie na wzrost efektywności procesu, natomiast bezpieczna temperatura, do której można schłodzić kompost nie powinna przekroczyć 52°C (co gwarantuje jego czystość pod względem sanitarnym). Zaobserwowano również, że wraz z wydłużaniem się wieku kompostu maleje efektywność procesu odzyskiwania ciepła.

Summary

The objective of the project was to find out whether the composting process of municipal waste may be used as a low temperature heat source. It was determined that during high temperature phase of the process on average 930.5 kJ of heat is produced per kg of compost. The designed and made laboratory model was used for carrying out three stages of testing, boiling down to running the composting process with parallel heat recuperation from the process. Basing on the tests, the parameters having affecting the heat recuperation process effectiveness were determined, viz.: optimum initial temperature of cooling water should be approximately 30°C, the reduction of flow rate of the cooling water has advantageous impact on the increase of process efficiency, whereas the safe temperature lower limit for compost cooling should be higher than 52°C (which safeguards compost sanitary purity). It was also observed that in parallel to compost age heat recuperation process efficiency is declining.

INTRODUCTION

One of the essential problems of our times is proper production of sufficient volume of energy. The energy consumption is swelling rapidly, fuel reserves are limited, and their constant use has frequently adverse impact on natural environment [7, 9]. Therefore, more and more emphasis is put on the use of non-conventional heat sources including also low temperature heat. Such sources may include heat produced from renewable sources of energy for domestic purposes. More and more frequently one may come across the application of biomass as a source of renewable energy. Other sources of heat may also include biothermal techniques for municipal waste disposal in composting piles, and biothermal chambers and mechanized lines for accelerated composting.

The transformations during composting process take place under the influence of microbiological processes in aerobic environment [6, 10, 13]. Consequently, a substantial amount of heat is released, part of which if the amount of waste is high enough, is accumulated in the layer and increases the temperature. At the beginning of the processes, during intensive composting phase, the temperature raises and ranges from 40°C to 75°C for the period of approximately two weeks. The course of compost temperature changes and the length of high temperature phase may vary and whether temperature is close to the lower or higher values of the range will depend on the technology applied and composition of the biomass under composting [1–3 5, 6, 8, 11]. Despite existing differences in the temperature values and in the length of high temperature phase, in all cases mentioned above the obtained compost was fit for further use, i.e. pure in sanitary terms.

Therefore, a thesis may be brought forward that the compost temperature reduction by a few or several Kelvins should not stop the composting process, but at the same time will allow taking away a certain heat volume, and making practical and economic use of it.

The municipal waste composting process has nowhere been tested from the perspective of energy recuperation using membrane heat exchangers. The composting effects with parallel compost temperature reduction through taking heat away from it have not been observed before. Such comprehensive testing programme covering this issue has been carried out at the Environmental Engineering Faculty, Warsaw University of Technology.

TESTING METHODOLOGY

For testing purposes heating compost was used, produced by RADIOWO Compost Producer, Warsaw, using DANO technology applied to domestic waste.

In the DANO system the process line comprises biostabilizer's loading equipment and compost cleaning equipment such as: sieves, hard particles separators, and electromagnetic separators. The biostabilizer consists of a rotary steel drum, 2/3 of which is occupied by waste, where waste is aerated. The composting process is initialized in here. Inside the drum the temperature of the feedstock increases up to approximately 45°C. After approximately 30 hours the waste is removed from biostabilizer and, so called heating compost, is dispatched into boxes, and then it is transported to piles where further composting process takes place. For testing purposes approximately 100 kg of heating compost from boxes was sampled. A high temperature composting process was continued in artificially aerated bioreactor at the laboratory.

A testing stand was so designed and constructed that composting process with simultaneous heat recuperation could be run (Fig. 1).

Laboratory model of container for running composting process was made of steel sheet and insulated with glass wool in order to reduce heat losses through its wall, characterized by thermal conductivity coefficient $\lambda = 0.0326$ W/mK (insulation layer 10 cm thick). It had a cylindrical shape with the following dimensions: $d_{int} = 0.7$ m, h = 0.77 m and total cubic capacity of 0.269 m^3. At the bottom, at the distance of 7 cm from the bottom, a steel grate was installed with circular holes 1 cm in diameter.

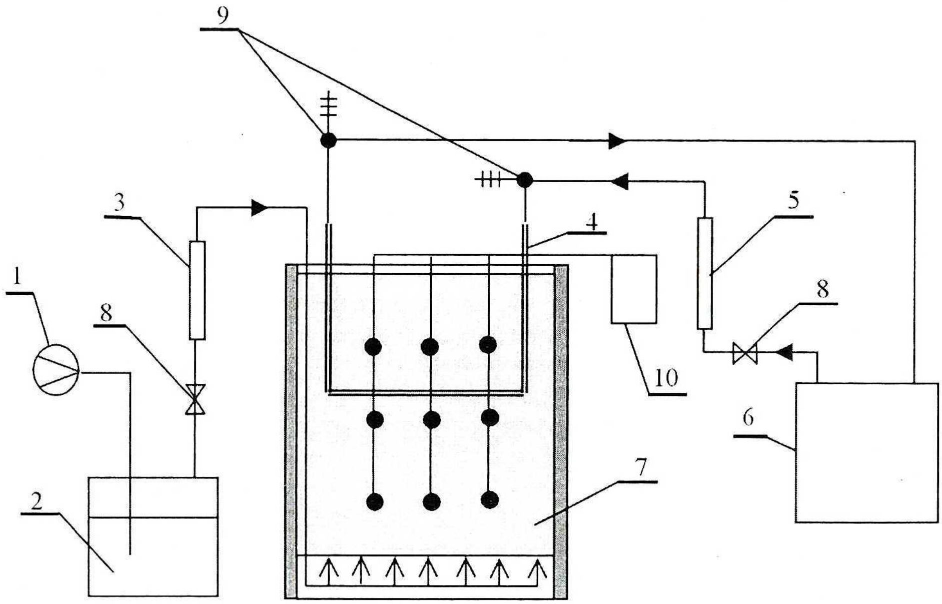

Fig. 1. Block diagram of system for heat recuperation from municipal waste composting process: 1 – compressor, 2 – washer, 3 – gaseous rotameter, 4 – membrane heat exchanger, 5 – water rotameter, 6 – ultrathermostat, 7 – container filled in with compost, 8 – ball valve, 9 – thermometers, 10 – compost temperature recorder

The container filled in with compost was aerated using AIRPUMP HP-60 Hiblow air compressor [1] with the average capacity of 2.3 m^3/h. The air was flowing through the washer with water [2] (air humidity reached 100%), and then through rotameter [3] and was fed into the compost container from the bottom [7].

Water heated up in ultrathermostat [6] to a certain set in advance temperature level flowed through rotameter [5] and entered the membrane heat exchanger [4] where thermometers had been installed at its insulated inlet and outlet [9]. Water temperature was measured with accuracy to 0.1 K.

Changes of temperature and volume of cooling water fed into the system allowed to carry out testing under variable cooling circumstances. Parallelly the influence of cooling was observed on the course of composting process through continuous recording of compost temperature values at its various depths and widths.

Compost temperature values were being recorded continuously. Temperature was measured with accuracy to 0.1 K. Temperature sensors had been distributed in the manner allowing to observe as accurately as possible the influence of cooling on the composting process. Temperature sensors had been placed at various depths and widths of the bioreactor. Sensors had been located at three depths of the compost layer: 18 cm (at this level heat exchanger had been mounted), 34 cm and 44 cm measured from the upper level of the compost layer, which accounted for 0.27; 0.5 and 0.65 of the thickness of compost layer and at a distance of 15 cm (EDGE), 23 cm (BETWEEN) and 35 cm (CENTRE) from container walls.

Temperature recorder [10] had been hooked up to a personal computer and using WINLOG 5 software the obtained results were being registered continuously and presented graphically. An assumption was made that a guarantee of compost purity in sanitary terms is to maintain compost temperature at the level of 50°C and above for the period of 10 days [10].

For the purposes of this project, a heat exchanger was designed and made to recuperate heat from compost. The heat exchanger was made of copper conduit with geometrical dimensions $d_z \times g = 0.018 \times 0.0015$ m and total length of 4.2 m. It was formed in such a way that the distances between pipes were 10 cm, while the distance of the external circumference of the heat exchanger from the container walls at any point was also 10 cm.

The heat exchanger was placed inside the container at the depth of 18 cm (from the upper compost level). Since the compost tends to settle, the heat exchanger was placed on the compost layer and thanks to such arrangement the heat exchanger was settling together with compost and was always at the level of approximately 2/3 of the height of compost feedstock (from the bottom of the container).

The volume of heat recuperated was calculated using the following formula:

$$Q_k = \frac{V_w \times \rho \times c_p (t_{out} - t_{in})}{3600}$$

where:

Q_k – heat recuperated from composting process [W],
t_{out} – water temperature at the heat exchanger outflow [°C],
t_{in} – water temperature at the heat exchanger inflow[°C],
c_p – mean water specific heat [J/kgK],
V_w – volume of water flow [dm^3/h],
ρ – mean water specific density [kg/dm^3],

Periodically, every couple of days, compost samples were taken and compost's physical and chemical properties were determined: moisture content in compost according to Polish Standard PN-88/B-04481, total organic matter content according to Polish Standard PN-88/B-04481, organic carbon content (Corg) according to Polish Standard PN-91/Z-15005 and for samples at the beginning and at the end of composting process in the container their calorific value was determined according to Polish Standard PN-93/Z-15008.04, and then using the difference, the heat volume produced during the high temperature phase of composting process was determined [4].

Three testing series called Stages: I, II and III were run. Differences among the individual stages stemmed from the fact that heat recuperation process parameters were changed. These included: process running time, initial temperature values and cooling water flow rate.

RESULTS AND DISCUSSION

Stage I

Changes of physical and chemical parameters of compost for this Stage are presented in Table 1.

Table 1. Moisture values, Corg and Total Organic Matter (TOM) for compost at Stage I

Date	Moisture content %	TOM % of dry mass	Corg % of dry mass
2001.03.06	40.00	54.76	25.94
2001.03.22	34.13	51.81	24.87
2001.03.30	39.41	50.68	24.00
2001.04.06	46.01	46.76	19.66
2001.04.13	34.07	44.76	19.40

Heat recuperation process was run using water with the following parameters: 20°C and 30 dm^3/h, and 15°C and 60 dm^3/h. Cooling process lasted for 120 minutes. The average values of recuperated heat volume are presented in Figure 2.

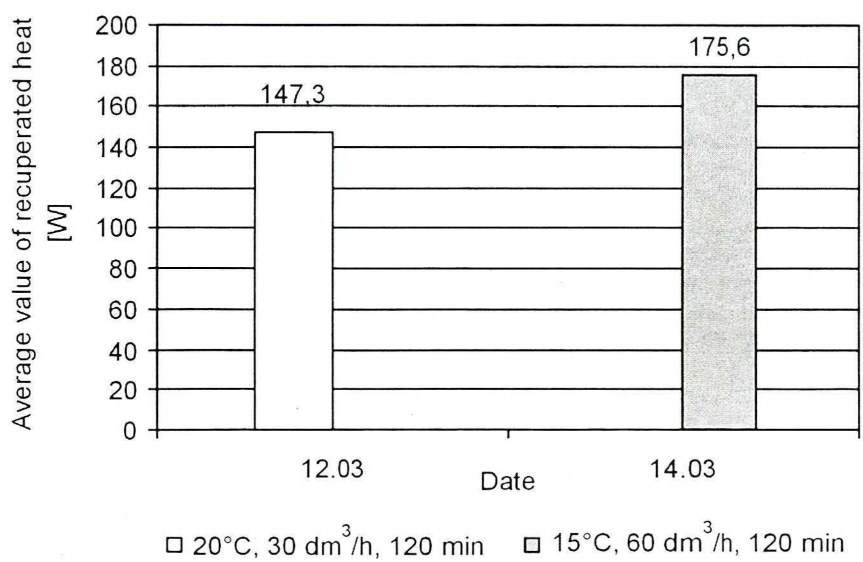

Fig. 2. Average values of recuperated heat volume from composting process as a function of process parameters at Stage I

In parallel compost temperature values were measured. Changes in temperature values at various depths and widths are presented in Figure 3.

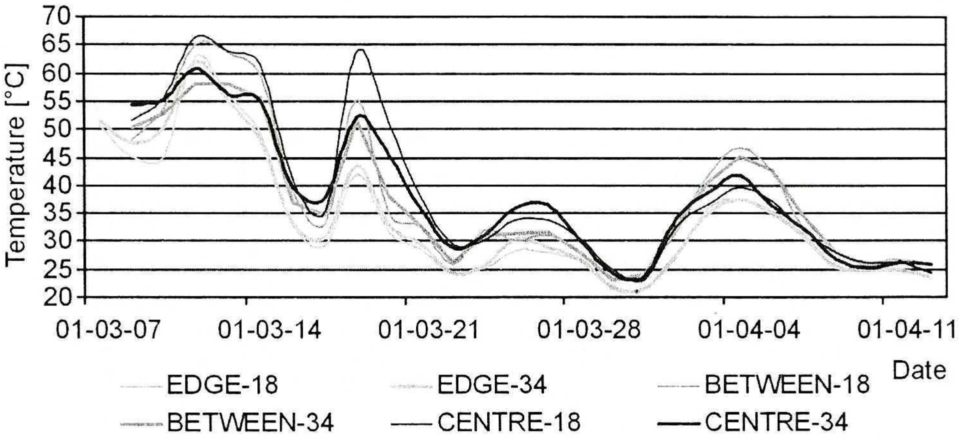

Fig. 3. Change of compost temperature values at various depths, for Stage I

The analysis of the above figure showed that as a result of cooling with water with parameters of 15°C and 60 dm^3/h the compost temperature declined below 50°C and despite attempts of air flow control and improvement of compost moisture content, it did not raise to approximately 60°C any more. The compost mass was cooled too much, which made the high temperature phase of composting process come to a halt. The values of physical and chemical parameters of compost (Tab. 1) were specific to the compost used during industrial scale composting process [10], therefore the compost temperature decline was caused by too low temperature of cooling water rather than compost quality.

Stage II

Changes of physical and chemical parameters of compost are presented in Table 2.

Table 2. Moisture content values, Corg and TOM and calorific values for compost at Stage II

Date	Moisture content %	TOM % of dry mass	Corg % of dry mass	Calorific value kJ/kg
2002.02.09	39.66	44.39	21.59	3417
2002.02.12	38.31	42.69	20.02	
2002.02.18	39.53	41.18	18.87	
2002.02.22	43.15	40.46	18.67	2448
Heat volume produced during composting process				969

At Stage I due to too low temperature of cooling water compost was cooled too much and high temperature phase of composting process came to a halt, therefore at this testing stage heat recuperation process duration was reduced to 40 and 20 minutes and water with higher initial temperature was applied: 25°C, 30°C and 35°C. The applied flow rates of cooling water were as follows: 120 dm^3/h, 90 dm^3/h, 75 dm^3/h and 60 dm^3/h. The obtained results are presented in Figure 4. The markings: 14.02 I, 14.02 II imply first and second cooling process on the same day, respectively.

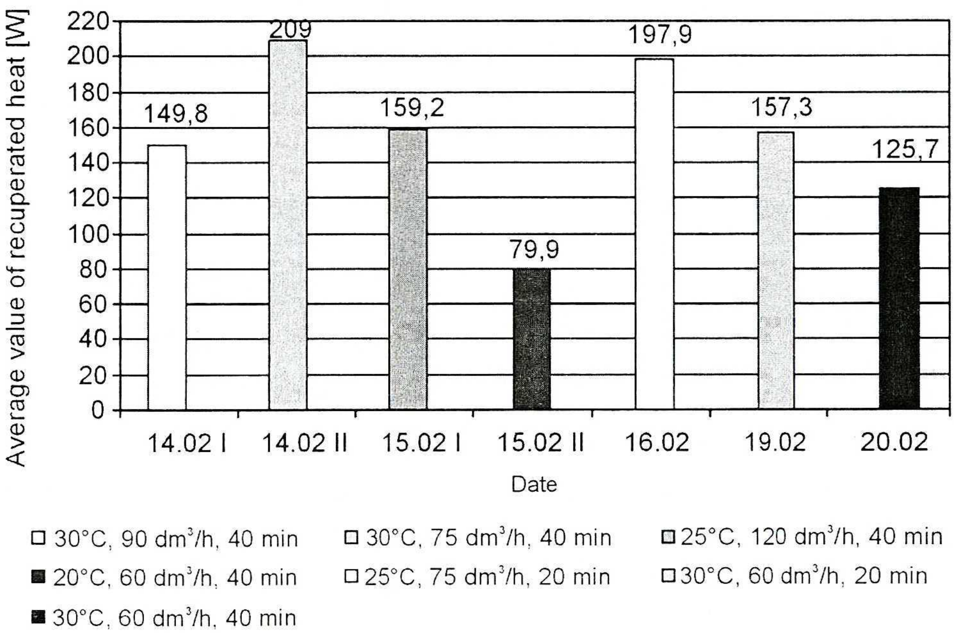

Fig. 4. Average values of recuperated heat volume from the composting process depending of process parameters at Stage II

Basing on the analysis of obtained results (Fig. 4) the increase in efficiency of heat recuperation process was observed paralleled by the declining water flow rates. The application of water with the initial temperature values of 25°C and 30°C increased the efficiency of recuperated heat volume (against Stage I testing), however, already for water with the initial temperature of 35°C considerable decline in process efficiency was observed, (the average value was 79.9 W, while for water with temperature of 20°C, with the same cooling time and flow rate, the average heat volume recuperated was 197.9 W). The decline of efficiency of heat recuperation at the end of composting process in reactor was also observed when compost temperature was on average 55°C. At the same time the influence of cooling at the compost temperature values was being observed. The changes of these values are presented in Figure 5.

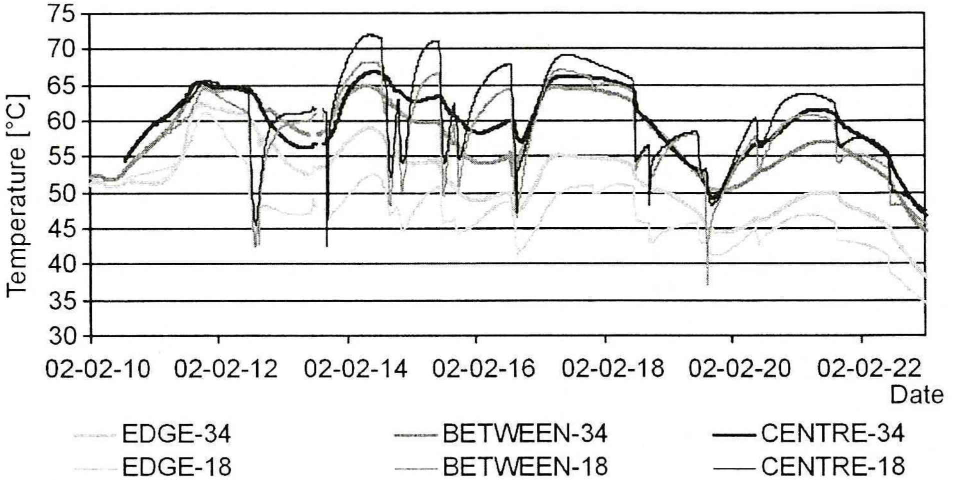

Fig. 5. Change of compost temperature values at various depths, at Stage II

When analyzing the influence of cooling of compost temperature values a number of dependencies were observed. The largest impact of cooling was observed at the spot marked as EDGE, where temperature would drop below 50°C and for the 18 cm deep layer (at this level heat exchanger was installed); at this spot, however, for compost initial temperature of 65–67°C, it was possible to maintain temperature above 50°C. Other compost layers were affected by cooling marginally, temperature declined by a few Kelvins. It was noticed that compost temperature bouncing time, once cooling was switched off, was growing along with compost age (initially it was 5 hrs, and at the end of composting process 17 hrs) and depended on the value of initial temperature of cooling water (for 30°C it was approximately 6 hrs, and for 25°C – 9 hrs).

Stage III

Changes of compost physical and chemical parameters are presented in Table 3.

Table 3. Moisture content values, Corg and TOM and calorific values for compost at Stage III

Date	Moisture content %	TOM % of dry mass	Corg % of dry mass	Calorific value kJ/kg
2002.03.20	43.24	44.58	20.69	3264
2002.03.29	44.03	42.15	18.98	
2002.04.02	35.07	38.81	17.10	
2002.04.06	40.46	38.12	16.83	2372
Heat volume produced during composting process				892

Heat recuperation process duration was extended to 60 minutes. The research was carried out for the initial temperature of cooling water: 25°C and 30°C, for lower values of water flow rates than at Stage II: 45 dm^3/h and 30 dm^3/h and tests were repeated for 30°C and 90 dm^3/h. Since the increase of water temperature during these tests was on average 5 K, at 30 dm^3/h flow rate, the heat recuperation process was run for the cooling water with the initial temperature values of 35, 40 and 45°C. Test results are presented in Figure 6.

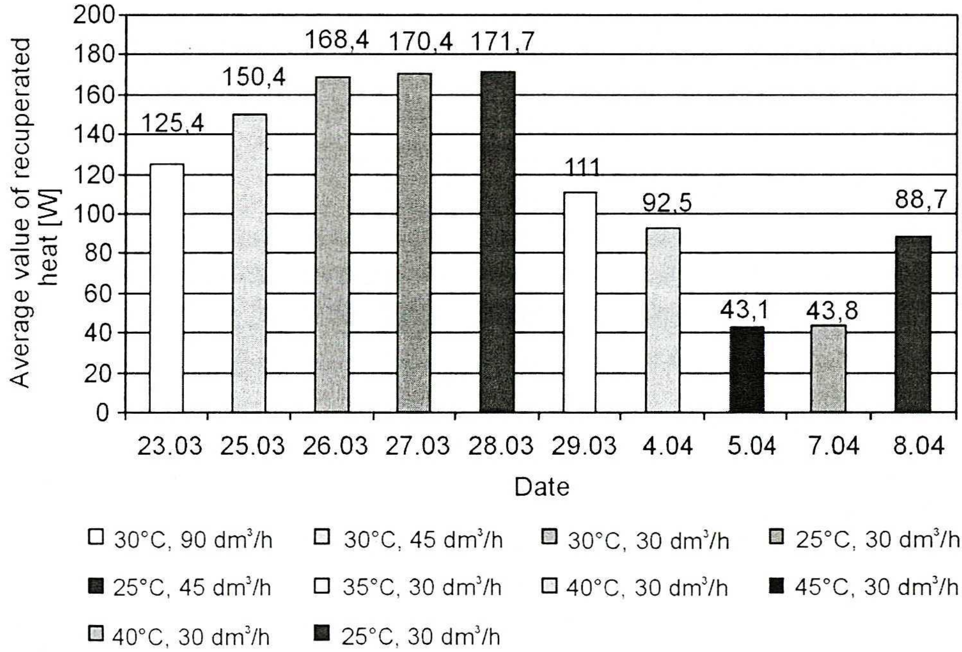

Fig. 6. Average values of the heat volumes recuperated from the composting process as a function of process parameters at Stage III

The reduction of cooling water flow rate was paralleled by the increase of efficiency of the process of heat recuperation from composting. The extension of cooling time reduced the average efficiency of the heat recuperation process, on average, by 30%, against the heat volume recuperated in the initial 40 minutes. The increase of cooling water temperature up to 35, 40 and 45°C led to the considerable decline in efficiency of recuperated heat volume. The obtained results allow to estimate that from the compost weighting 500 kg (approximately 1 m^3), when a heat exchanger with heat exchange surface five times larger than that used in the tests (5 x 0,226 m^2) is applied, water flow rate is 30 dm^3/h, the initial water temperature is 25°C, it is possible to heat up water to the temperature of 48°C, with 585 W of heat recuperated on average.

When analyzing Figure 6 it was also noticed that in line with compost age the efficiency of heat recuperation process was declining. On 28th March when water parameters were 25°C and 30 dm^3/h the average volume of heat recuperated for compost was 170.4 W, whereas on 8th April, when cooling water with the same parameters was used, the average volume of heat recuperated for compost was 88.7 W.

In parallel to the composting process, compost temperature values were being registered.

The changes of temperature values are presented in Figure 7.

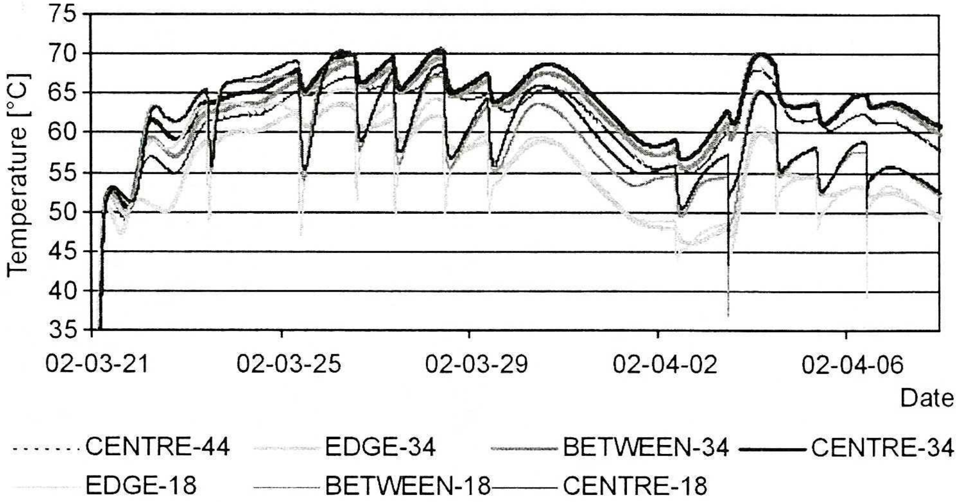

Fig. 7. Change of the compost temperature values at various depths, at Stage III

Despite the extension of cooling time, but applying lower water flow rates (against Stage II), except for the spot marked as EDGE, compost temperature was kept at the level higher than 50°C for 10 days, which guaranteed its purity in sanitary terms. Similarly to Stage II the extension of compost temperature bouncing time was observed (once cooling was switched off) and along with compost ageing (initially 4 hrs, at the end of composting process 21 hrs) and in parallel to the declining of cooling water initial temperature (30°C – 6 hrs, 25°C – 16 hrs). Along with compost ageing a growing influence of cooling on the temperature of more remote compost layers was observed (BETWEEN-34, CENTRE-34, EDGE-34, CENTRE-44). It was noticed that for compost temperature (prior to the start of cooling process) falling into 65–67°C bracket, the switching off cooling at compost temperature not lower than 52°C, allowed to keep compost temperature above 50°C.

CONCLUSION

The obtained test results allow to determine parameters affecting on the efficiency of the process of heat recuperation from the municipal waste composting process. These parameters are as follows:

- Average heat volume produced during high temperature phase of the composting process amounts to 930.5 kJ/kg of compost.
- With the reduced cooling water flow rate, the increase of efficiency of heat recuperation process has been observed.
- Optimum initial temperature of cooling water is 30°C. The application of water with higher temperature causes the decline of the volume of heat recuperated, while the application of water with lower temperature – leads to much longer bouncing time of compost temperature once cooling has been switched off. The application of water with the initial temperature of 15°C may inhibit high temperature phase of composting process.

- Compost cooling safe temperature is 52°C. The reduction of compost temperature below that value, results in temperature drop below 50°C, which does not guarantee compost purity in sanitary terms;
- Along with compost ageing the efficiency of heat recuperation process is declining. Lower volumes of heat are recuperated, the compost temperature bouncing time gets extended and the impact of cooling on temperature values of more remote compost layers is raising.
- Cooling had the highest impact on the temperature of compost layer located nearest to the heat exchanger, but already at a distance of 16 cm and 26 cm (layers marked as 34 and 44) the impact was quite small. This will allow to apply a battery of heat exchangers for heat recuperation from composting process in the future.

The obtained test results show that thanks to the selection of proper parameters of heat recuperation process that do not inhibit the composting process, it will be possible not only to obtain compost pure in sanitary terms and after further processing fit for further use, but also to recuperate low temperature heat. It is necessary, however, to further test the cooling process using lower water flow rates, cooling time extended and defining the compost age impact on the efficiency of heat recuperation process.

The research project was funded by the Scientific Research Committee in Warsaw in 2003.

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Received: April 6, 2004, accepted: October 4, 2004