ARCHIVES OF ENVIRONMENTAL PROTECTION
ARCHIWUM OCHRONY ŚRODOWISKA
vol. 31 no. 1 pp. 83 - 94 2005

PL ISSN 0324-8461

© Copyright by Institute of Envionmental Engineering of the Polish Academy of Sciences, Zabrze, Poland 2005

RECOVERY OF HEAT IN THE AEROBIC PHASE OF COMPOSTING PROCESS OF MUNICIPAL WASTE

EWA KLEJMENT, MARIAN ROSIŃSKI

Warsaw University of Technology, Heating and Ventilation Institute, Environmental Engineering Faculty, ul. Nowowiejska 20, 00-653 Warszawa

Keywords: composting process, heat recuperation, heat exchanger.

ODZYSKIWANIE CIEPŁA W PROCESIE TLENOWEJ FAZY KOMPOSTOWANIA ODPADÓW KOMUNALNYCH

W celu doboru optymalnych warunków prowadzenia procesu odzyskiwania ciepła z tlenowego kompostowania przeprowadzono trzy etapy badań polegające na rejestracji wartości strumienia odzyskiwanego ciepła wraz z obserwacją wpływu chłodzenia na parametry procesu kompostowania. Zmierzono wartości współczynnika przewodności cieplnej kompostu w zależności od jego temperatury, gęstości i wieku. Wartości wahały się w granicach: 0,171–0,300 W/mK. Dobrano optymalne warunki prowadzenia procesu. Dla nich oszacowano, ile ciepła można będzie odzyskiwać podczas kompostowania na skalę przemysłową przy zastosowaniu baterii wymienników. Dla sztucznie napowietrzanej pryzmy o wymiarach: podstawa dolna 8 m, podstawa górna 5 m, wysokość 3,5 m, długość 3 m; można będzie odzyskiwać około 7,4 kW (z 1 m^2 powierzchni wymiennika 774 W).

Summary

In order to select the most optimum parameters for running heat recuperation process from aerobic composting process, three testing stages were run involving the registration of the value of recuperated heat volume and the observation of cooling impact on composting process parameters. The values of thermal conductivity coefficient were measured as a function of compost temperature, density and age. The values ranged from 0.171 to 0.300 W/mK. The optimum parameters for process running were selected. Basing on them it was estimated how much heat will be possible to recuperate during the composting process on industrial scale using a battery of heat exchangers. For artificially aerated pile with the following dimensions: lower base 8 m, upper base 5 m, height 3.5 m, length 3 m; it will be possible to recuperate approximately 7.4 kW (from 1 m^2 of heat exchanger surface – 774 W).

INTRODUCTION

Changes during composting process are caused by microbiological processes in aerobic environment [6, 11, 15]. In the result a considerable amount of heat is produced, part of which when the amount of waste is sufficiently high, is accumulated in the waste layer and raises its temperature. During the intensive composting phase, at the beginning of the process, the temperature rises and hovers around 40–75°C for a period of approximately two weeks. The Environmental Engineering Faculty, Warsaw University of Technology, carried out tests to check possibilities of heat recuperation from aerobic composting of municipal waste. The obtained test results (presented in *Research on the Aerobic Composting of Municipal Waste with a View to Heat Recuperation* [7]), showed that thanks to the selection of appropriate parameters of heat recuperation process, the composting process in addition to waste disposal may also perform a function as a low temperature heat source. The test results [7] showed also a necessity of further research on the heat recuperated from the composting process with the focus on the extension of cooling duration, application of reduced water flow rates and measurement of the value of compost thermal conductivity coefficient. Thanks to such research it will be possible to select the most optimum parameters for running heat recuperation process.

TESTING METHODOLOGY

For testing purposes these was used heating compost, produced by RADIOWO Compost Producer, Warsaw, using DANO technology applied to domestic waste. Approximately 100 kg of heating compost was sampled from boxes. A high temperature composting process was continued in artificially aerated bioreactor at the laboratory. A detailed description of testing stand allowing to run composting process with simultaneous heat recuperation was presented in the earlier article [7].

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

Temperature sensors were located at three depths of the compost layer: 18 cm (at this level heat exchanger was 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 the container walls. 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 [11].

Periodically, every couple of days, compost samples were taken and its physical and chemical properties were determined: moisture content in compost according to Polish Standard PN-88/B-04481, total organic matter (TOM) content according to Polish Standard PN-88/B-04481, organic carbon content (Corg) according to Polish Standard PN-91/Z-15005. For samples at the beginning and at the end of composting process in the container their calorific values were 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]. The compost thermal conductivity coefficient was measured using the Bock's plate apparatus (so called Bock's table) as a function of compost temperature, density and age. The temperatures of compost incoming and outgoing air were registered. The values of heat removed with air from the system were determined [12] (for Stages IV and V).

Three testing series called Stages IV, V and VI were run. The 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. At Stage VI older compost was used for testing i.e. it stayed in pile for 5 days.

RESULTS AND DISCUSSION

Stage IV

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

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

Date	Moisture content %	TOM % of dry mass	Corg % of dry mass	Calorific value kJ/kg
2002.0523	35.00	48.26	24.70	4116
2002.05.30	42.92	46.51	23.54	
2002.06.02	33.33	42.05	20.67	
2002.06.08	42.41	39.37	18.13	2310
Heat volume produced during composting process				1806

At this testing stage the heat recuperation process duration was extended to 90 and 120 minutes. The tests were run for water with the initial temperature of 25°C and 30°C and for cooling water flow rates lower than at Stage III [7]: 45 dm^3/h, 30 dm^3/h and 20 dm^3/h. The average values of recuperated heat volumes are presented in Figure 1.

In parallel the compost temperature values were measured. The changes of temperature values at various depths and widths of tested compost are presented in Figure 2.

Basing on the analysis of the above figures (Fig. 1 and 2) it was observed that the highest mean value of heat volume was obtained for cooling water with the initial temperature of 25°C and flow rate of 25 dm^3/h, however, the compost temperature bouncing time at the depth of 18 cm (at the same depth heat exchanger is located) after switching off cooling system was 16 hrs, while for cooling water with the initial temperature of 30°C it was below 6 hours. The increase of the volume of recuperated heat was observed in parallel to the decline in the cooling water flow rate. For water with the initial temperature of 30°C the highest volumes of recuperated heat were recorded for the flow rate of 20 dm^3/h, while the extension of cooling time from 90 to 120 minutes reduced slightly the volume of heat recuperated (by 1%). For cooling water with the following parameters: 30°C, 30 dm^3/h and 30°C, 45 dm^3/h higher decline of heat recuperated was observed in parallel to the extension of cooling time from 90 to 120 minutes (by 23% and 28% respectively). This may be a result of the compost age impact on the efficiency of heat recuperation process [7]. The lower compost temperature values were recorded for the spots marked as EDGE. Dependence was also observed that the older the compost was the longer compost temperature bouncing

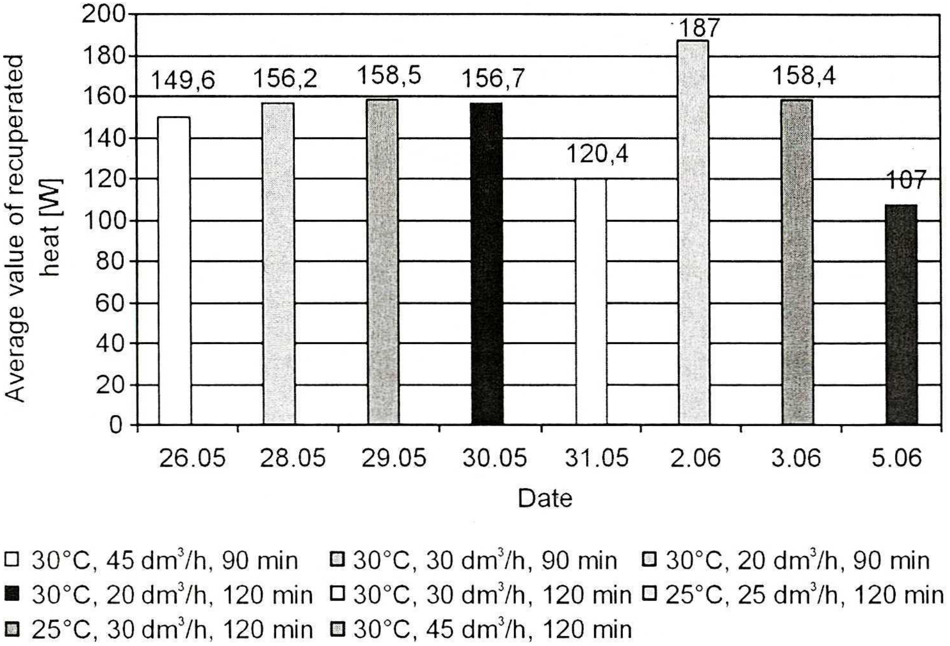

Fig. 1. Average values of recuperated heat volume from the composting process depending of process parameters at Stage IV

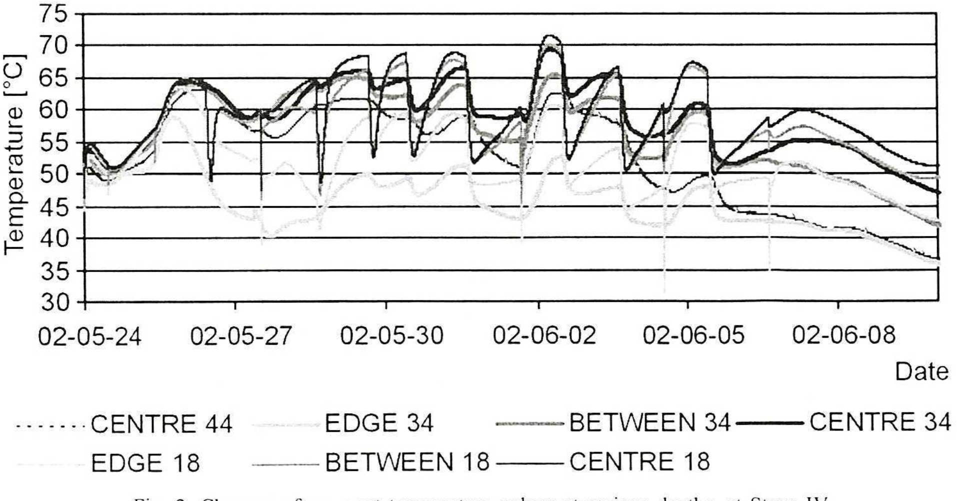

Fig. 2. Changes of compost temperature values at various depths, at Stage IV

time was after switching off the cooling system. For compost layers located at the same level as heat exchanger (marked as 18) for 6-day-old compost the bouncing time was below 6 hrs, while for 14-day-old compost it was 26 hrs (the temperature did not return to the level before cooling). A growing impact of cooling was observed along with compost ageing on the temperature values of more remote layers (marked as 34 and 44). This dependence may be also driven by the impact of compost age on the value of compost thermal conductivity coefficient. Therefore, the value of coefficient was measured for fresh compost (with density of 442 kg/m^3 and moisture content of 42.9%) and for 17-day-old compost (with density of 515 kg/m^3 and moisture content of 42.4%), for various temperature values. The obtained results are presented in Figure 3.

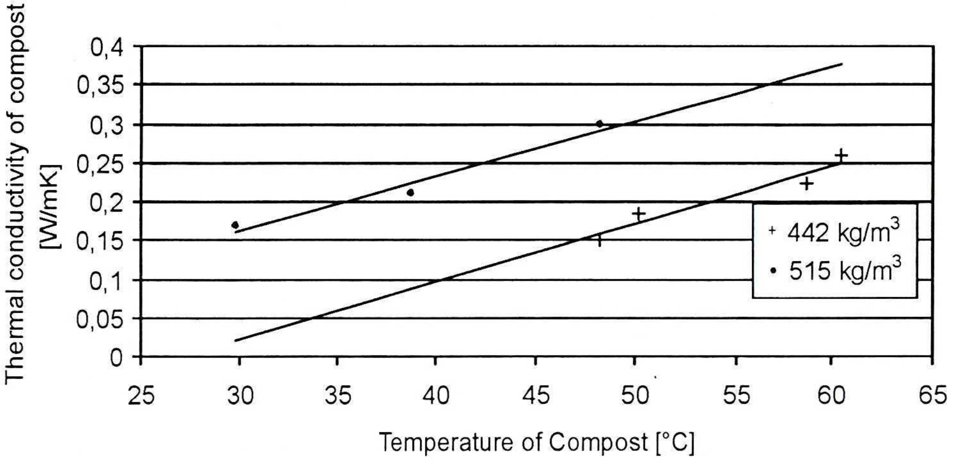

Fig. 3. Change in the value of compost thermal conductivity coefficient depending on compost temperature, density and age

The obtained results (Fig. 3) confirmed that together with compost age grows the value of compost thermal conductivity coefficient. This is caused by the change of compost chemical

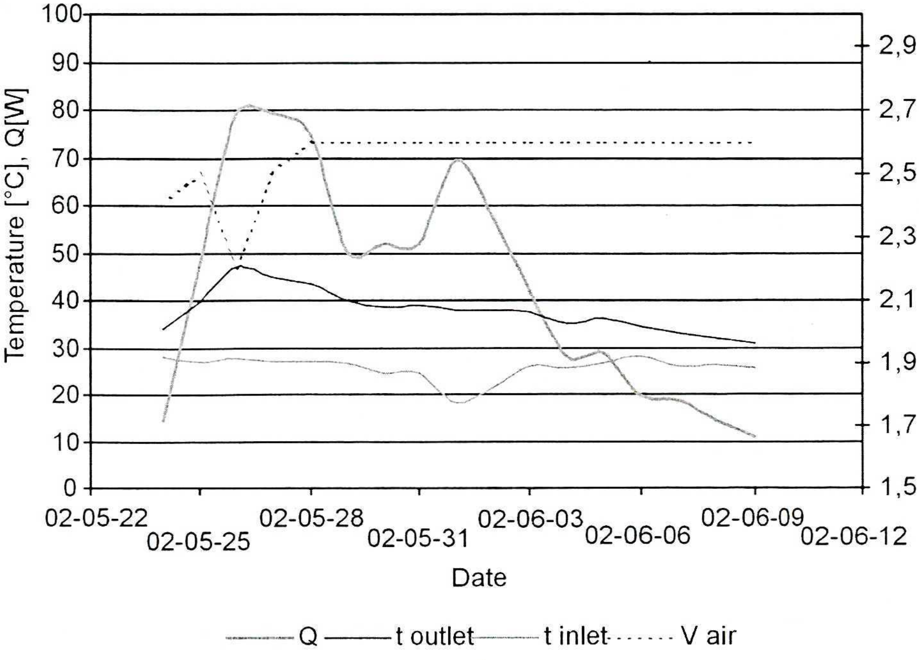

Fig. 4. Course of changes in the value of incoming and outgoing air, and flow rate and heat removed with the air at Stage IV

composition caused by biochemical changes, and change of its temperature and density.

In parallel the compost aeration parameters were registered and the heat volume removed from the air was calculated. The course of changes of these parameters is presented in Figure 4.

The volumes of heat removed with the air were the highest during the initial six days of process running. The heat volumes depended on the difference between the outgoing and incoming air and on the value of air flow stream. During the initial six days, on average, 20 W per 1 m^3 of air was removed per hour.

Stage V

The changes of physical and chemical parameters of compost for this stage are presented in Table 2.

Table 2. Moisture values, Corg and Total Organic Matter (TOM) and compost calorific values for compost at Stage V

Date	Moisture content %	TOM % of dry mass	Corg % of dry mass	Calorific value kJ/kg
2002.07.12	41.30	54.29	22.31	4224
2002.07.20	44.59	53.62	21.71	
2002.07.24	50.00	51.05	19.75	
2002.07.26	40.00	50.00	18.91	3346
Heat volume produced during composting process				878

At this testing stage the heat recuperation process was run for cooling water with the temperature of 30°C by reducing flow rate to 15 dm^3/h and 10 dm^3/h; the process run time was 120 minutes. The heat recuperation process was also run using cooling water with the following parameters: 20 dm^3/h and 30°C, extending process time to 180 minutes. The average volumes of heat recuperated are presented in Figure 5.

Basing on the analysis of the obtained test results (Fig. 5) a decline in the efficiency of heat volume removed from the composting process was observed parallelly to the decline in the cooling water flow rate. In the latter case it was also true for the increase of temperature of heat exchanger feeding water. The highest efficiency of heat recuperation was recorded for the process with the water with the parameters of 30°C and 20 dm^3/h.

Parallelly the changes in the compost temperature at various depths were registered. The obtained results are presented in Figure 6.

The lowest values of compost temperature (similarly to the Stage IV) were registered for the spots marked as EDGE. When cooling system was switched off, and compost temperature was declining below 53°C, the temperature decline continued to the level lower than 50°C, which did not guarantee compost purity in sanitary terms [11]. It was the case for cooling with water characterized by the following parameters: 30°C, 20 dm^3/h and 180 minutes, which implies that running time of heat recuperation process was too long. Like at the previous stage the extension of cooling temperature bouncing time was observed in parallel to the compost ageing (for 6-day-old compost it was below 6 hrs, while for 11-day-

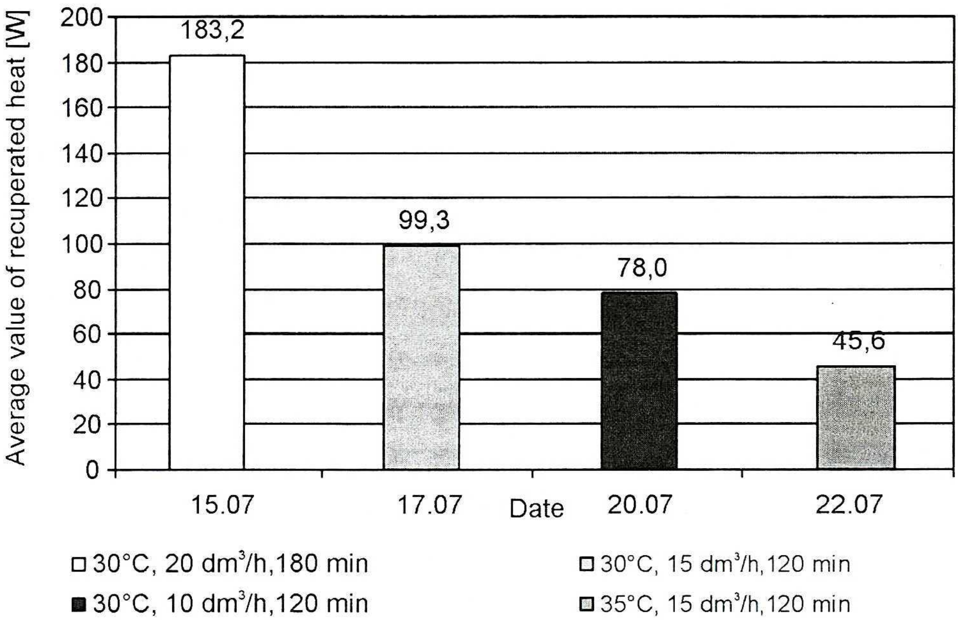

Fig. 5. Average volumes of heat recuperated from the composting process depending on process parameters at Stage V

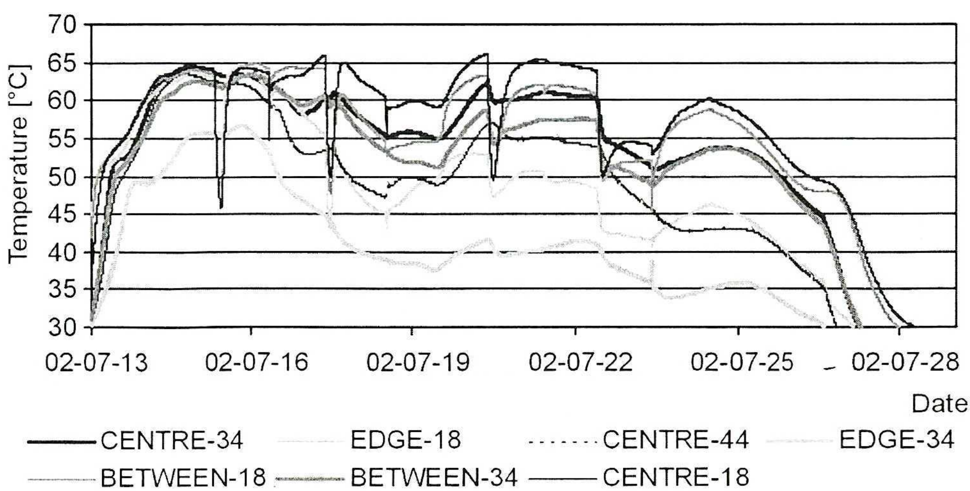

Fig. 6. Changes of compost temperature values at various depths at Stage V

old compost it rose to 19 hrs for the level marked as 18). In line with the compost age the impact of cooling on the temperature decline in more remote compost layers was growing (marked as 34 and 44).

The compost aeration parameters were registered and the heat volume removed with the air was calculated. The course of these parameters is presented in Figure 7.

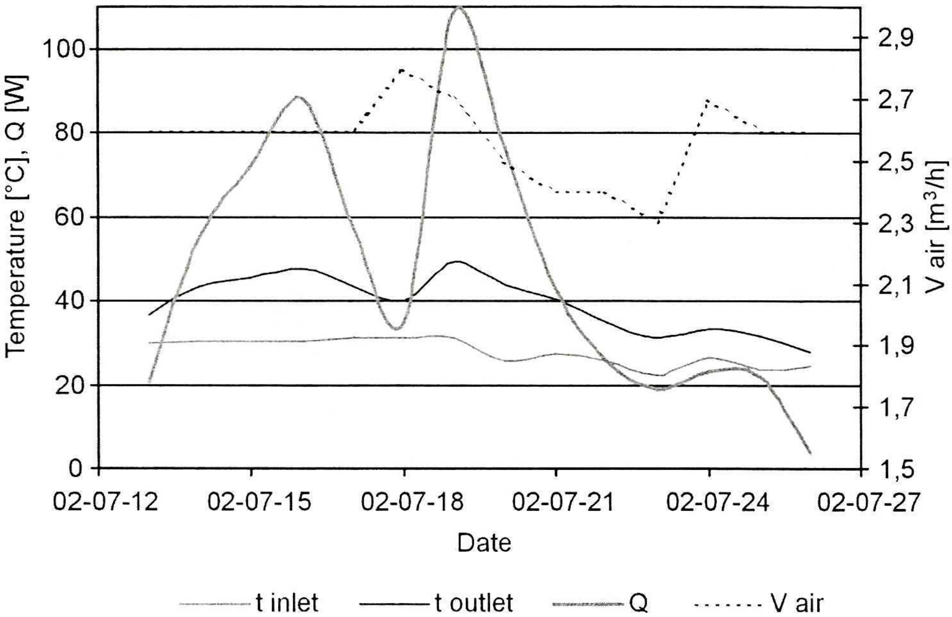

Fig. 7. Course of changes in the incoming and outgoing air temperature values, flow rate and heat removed with the air at Stage V

Like at Stage IV the values of heat volume removed with the air were the highest during the initial seven days of process running. On the seventh day the value of heat volume removed reached the level of 110 W, which was caused by too high value of flow rate of fed air. During the initial six days on average 19.8 W of heat was removed per hour expressed per 1 m^3 of air.

Stage VI

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

Table 3. Moisture values, Corg and Total Organic Matter (TOM) and compost calorific values for compost at Stage VI

Date	Moisture content %	TOM % of dry mass	Corg % of dry mass	Calorific value kJ/kg
2002.07.31	41.21	55.53	25.36	4264
2002.08.05	40.23	53.28	23.46	
2002.08.08	37.63	52.43	22.92	
2002.08.13	40.15	51.02	22.29	3611
Heat volume produced during composting process				653

Since at earlier testing stages a decline in the efficiency of heat recuperation from compost was observed along with compost age, for this testing stage older compost was used i.e. 5 day old, and the first cooling was applied to 9-day-old compost. The aim of this test was to check if compost age has impact on heat recuperation process effectiveness, or whether the decline in effectiveness is caused by the fact that compost is "spent" due to earlier cooling. The tests were run for cooling water with the initial temperature of 30°C and the following flow rates: 60 dm^3/h, 45 dm^3/h and 10 dm^3/h for 120 minutes, and for water with parameters 30°C and 30 dm^3/h the process duration was extended up to 180 minutes. The obtained test results are presented in Figure 8.

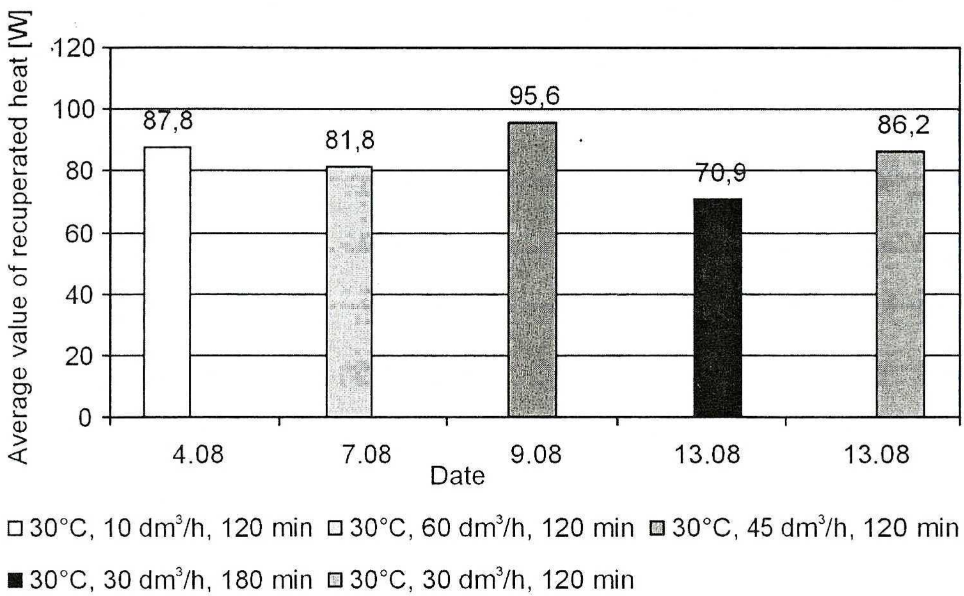

Fig. 8. Average values of heat volumes recuperated from composting process depending on the process parameters at Stage VI

At this testing stage, due to the application of older compost, lower volumes of heat were recuperated as opposed to the test with fresh compost not older than 10 days of age (Stage IV and tests described in article [7]). The decline in efficiency was in the range of 30–40% (converted into the same cooling time).

Parallelly to the composting process, the compost temperature values were registered. Their change is presented in Figure 9.

Similarly to the previous testing stages the increase of compost temperature bouncing time was observed after switching off the cooling system in line with compost ageing. For first cooling it was 10 hrs, and after the last cooling (19-day-old compost) temperature did not bounce off to reach the original values before cooling. The lowest temperature was recorded for the spots marked as EDGE. A higher decline of compost temperature due to cooling was recorded for layers marked as 34 and 44 as opposed to the previous testing stages where fresh compost was applied. For this testing stage the compost temperature values were the same as at the previous stages and the compost was not earlier subject to

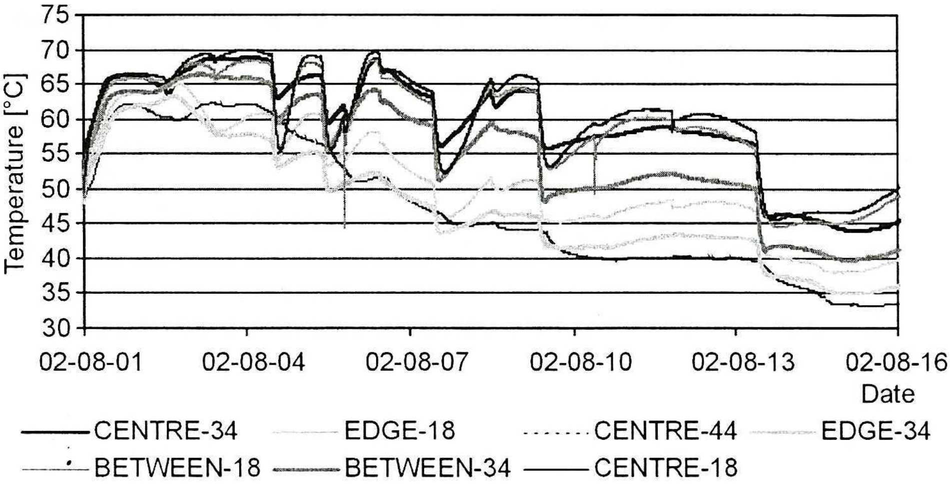

Fig. 9. Change of compost temperature values at various depths at Stage VI

heat recuperation. The results obtained at this stage allow to put forward a thesis that the decline of the efficiency of heat recuperation process was caused by the use of older compost for testing.

CONCLUSION

Basing on the comprehensive testing it was noticed that with appropriately selected parameters of heat recuperation process compost cooling will not have negative impact on the course of composting process (changes of physical and chemical characteristics during test performance were similar to those present during industrial scale [11]), and consequently it will be feasible to recuperate heat from the composting process. The heat volume produced during the high temperature phase of composting process ranged from 653 to 1806 kJ/kg. Taking into consideration the results obtained during previous testing stages [7] it can be assumed that the average value of heat produced was 904 kJ/kg.

Basing on the experimental testing of the heat recuperation from the compost (described earlier in this article and [7]) the most optimum parameters for process running were determined. These are as follows:

- Cooling process should be run in the laminar flow environment, the best performance obtained for the flow rate of 20–25 dm^3/h (Re = 622–691, α = 174.9–181.1 W/m^2K), high efficiency of the process was also recorded for the water flow rate of 30 dm^3/h (Re = 833–928, α = 192.7–199.7 W/m^2K).
- The initial temperature of cooling water should not be lower than 25°C, since it may lead to the excessive cooling of compost mass and consequently bring the composting process to a halt. The most optimum temperature for running cooling process is 30°C. When water with temperature of 25°C is applied it secures higher efficiency of heat recuperation process, however, it leads to extension of compost bouncing time after switching off the cooling system.

- Duration of heat recuperation process for which the best performance was recorded amounts to 120 minutes. The lengthening of process running time caused a considerable drop of compost temperature, which could bring the composting process to a halt.
- The optimum compost temperature, which is the most effective for running heat recuperation process, should be between 65–67°C. At higher compost temperature a larger drop of its temperature was recorded (as a result of cooling); when the temperature is lower the heat recuperation process effectiveness declines.
- Safe temperature level to which compost may be cooled down is 53°C. Cooling of compost below this temperature may lead to the decline of compost temperature below 50°C, which does not guarantee sanitary purity.
- For the composting process during the initial 5–6 days the safe distance between the heat exchangers may be 55 cm, (impact of cooling on more remote compost layers was not measured). The first heat exchanger may be located at a distance of 18 cm from the upper level of compost.
- The compost bouncing time after switching off the cooling system for the above mentioned cooling water parameters was getting longer and longer with compost age. For fresh compost it was approximately 6 hrs. Therefore it is beneficial to run heat recuperation process during the initial 5–6 days of composting process.
- The heat recuperation from compost is influenced by the value of thermal conductivity coefficient l. The tests carried out show that the value of l depends on temperature, moisture content, density and compost age.

From the above assumptions taken for heat recuperation process an estimate was made that heat volume can be recuperated from composting process on industrial scale.

Żygadło [14] specifies the dimensions that a pile with artificial aeration should have: width of lower base: 6–10 m, width of upper base: 4–6 m, height: 3–4 m, an arbitrary length. Taking mean values of the above dimensions (lower base: 8 m, upper base: 5 m, height: 3.5 m and pile length 3 m, aeration rate of 320 m^3/h) it was estimated how much heat can be recuperated from compost. In the pile designed as described above and with consideration given to the above conditions, it is possible to locate a battery comprising 172 heat exchangers, with heat exchange surfaces equal to those of the heat exchanger used during our testing.

Given that each of them will be fed with water with the initial temperature of 30°C and flow rate of 20 dm^3/h for 2 hours and that each heat exchanger will be used it is possible to recuperate, on average, 171 W (to maintain continuous operation: 2 hours of operation, 6 hour break; in one cycle 4 heat exchangers should be operational). As a result for such configuration the average volume of heat recuperated amounts to 7.4 kW (from 1 m^2 of exchanger surface it is possible to recuperate 774 W on average). Assuming that with 1 m^3 of outgoing air from the system within one hour on average 20 W is removed, it can be calculated that with pile aeration rate of 320 m^3/h, 6.4 kW of heat can be recuperated.

The obtained test results show that the composting process may be a function of low temperature heat source, which is of pivotal importance in present times when more and more emphasis is put on environmental protection through the application of unconventional heat sources.

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

REFERENCES

[1] Antolak T.: *Composting of municipal waste in Polish realities*, Handbook: Environment-friendly waste management at municipality level, http://www.most.org.pl/3r/poradn/6kompost.htm.

[2] Antolak T.: *Composting of municipal waste in Polish realities*, [in:] Conference materials from conference called „Techeko' 95", Cracow 1995, p. 88–89.

[3] Cornell Composting Science & Engineering: *Compost: compost physics, monitoring compost temperature, calculating the oxygen diffusion coefficient in air*, http://www.cfe.cornell.edu/compost.

[4] Guljajew N.: *Naucznyje trudy AKH. Sanitarnaja Oczistka Gorodow*, (Urban sanitary cleaning) **XXV**, 25, 19 (1964).

[5] Herhof – Composting System. *Equipment for composting municipal waste, promotional materials of Herhof Umwelttechnik.*

[6] Kaiser J.: *Modeling composting as a microbial ecosystem: a simulation approach*, Ecological Modelling, 91, 25–37 (1996).

[7] Klejment E., M. Rosiński: *Research on Aerobic Composting of Municipal Waste with a View to Heat Recuperation*, Archives of Environmental Protection, **31**, (1), 71–82 (2004).

[8] Millich E.: *European Union Strategy and instruments for promoting renewable sources of energy*, [in:] Materials from International Conference „Renewable Sources of Energy on the Eve of 21st Century" Warsaw 2001, p. 9.

[9] Murray Ch., J. Thompson, J. Ireland: *Process control improvements at composting sites*, BioCycle Journal of Composting & Recycling, **12**, 54–58 (1991).

[10] Rosiński M.: *Environmental impact of low and medium-power heat sources*, Monograph of Environmental Engineering Committee of the Polish Academy of Sciences, 2002, vol. 12.

[11] Skalmowski K.: *Composting of municipal waste. Technological solution models*, Scientific papers at the Environmental Engineering Faculty at the Warsaw University of Technology, bulletin 39 OWPW, Warszawa 2001.

[12] Szargut J.: *Technical Thermodynamics*, Wydawnictwo Naukowe PWN, Warszawa 1991, p. 197–218.

[13] Van Roosmalen G., J. Langerijt: *„Green waste" composting in the Netherlands*, BioCycle Journal of Composting & Recycling, **7**, 32–35 (1989).

[14] Van der Gheynst J., L. Walker, J. Parlange: *Energy transport in a high-solids aerobic degradation process: Mathematical modelling and analysis*, Biotechnol. Prog., **13**, 238–248 (1997).

[15] Żygadło M.: *Municipal waste management*, A publication of the Świętokrzyski University of Technology, Kielce 1999.

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