THE EFFECT OF AIR FLOW AND STIRRING FREQUENCY IN CONTINUOUS THERMOPHILIC COMPOSTING

Anni Rochaeni*[1], Bambang Ariantara[2], Lili Mulyatna[1], Arief Nugraha[1], Riza Apriansyah

[1]Department of Environmental Engineering, Universitas Pasundan, Indonesia
[2]Department of Mechanical Engineering, Universitas Pasundan, Indonesia

Abstract

Continuous Thermophilic Composting (CTC) was developed as a modification of continuous composting carried out in the thermophilic phase, where the organic waste degradation process runs quickly. Previous CTC research used lamps as a heat source, which was then changed to use a heater. Several important factors in composting are stirring and air circulation to increase oxygen levels so that the aerobic composting process occurs. The machine has been modified by making air holes and setting automatic stirring. This research aims to determine the air hole openings and stirring frequency that provide the best results. The research was carried out in 2 stages. The first stage is to look for air hole openings with 3 variations: closed, half open, and fully open. Continue by finding the best stirring frequency with 3 variations: once a day, 2 times a day, and 6 times a day. The parameters measured include temperature measured humidity and pH during the composting process, and chemical analysis of fresh waste, compost starter, and mature compost resulting from the process. The research was carried out for 8 days with the addition of 1 kg of artificial waste per day. The results showed that half-open air holes produced better compost quality and temperature consistency in the thermophilic phase. The stirring frequency of 2 times a day produces consistent temperature results in the thermophilic phase and compost quality that meets SNI 19-7030-2004 of Compost Specifications from Domestic Organic Waste.

Keywords: *Air hole, Continuous Thermophilic Composting (CTC), organic waste, stirring, temperature*

Introduction

Based on an analysis of waste composition in Indonesia, organic waste is the largest component, reaching over 70%, where kitchen organic waste reaches 20-65% depending on the economic class of the community (Damanhuri, 2005) (Yustiani et al., 2019a). The presence of organic waste accelerates the process of waste decomposition, giving rise to a disturbing odor. Currently processing using Black Soldier Flies (BSF) is widely used and proven to be effective (Rochaeni et al., 2021) (Mulyatna et al., 2022) . However, not everyone wants to deal with larvae. Previously, many household scale composters have been developed, however composters have several conditions for the success of the composting process, including optimal waste size and setting the process temperature (Damanhuri et al., 2014). Meanwhile, many users do not consistently cut the waste and also turn the waste so that the temperature of the composting process is controlled. This mostly happens to middle-high income communities who in fact contribute more to waste (Damanhuri et al., 2014) (Yustiani & Abror, 2019). For this reason, a household-scale composter that runs automatically is needed to shred the waste and turn the waste over automatically with a

*)Corresponding Author:
E-mail: anni_rochaeni@unpas.ac.id

Received: 11 March 2024
Revised : 13 March 2024
Accepted: 16 March 2024
DOI: 10.23969/jcbeem.v8i1.12958

temperature indicator (Rochaeni et al., 2021a). The CTC machine is modified by replacing the lamp with a heater, and will be tested with waste from various waste sources.

In general, the quality of compost really depends on the raw materials. Kitchen waste or food waste contains high levels of organic material such as dissolved sugar, flour, fat, protein, cellulose and other components which are highly biodegradable and generally contain few disturbing bacteria (Gill et al., 2014). Various forms of composters have also been developed. In composters with continuous waste intake, adding air holes at the top or bottom will increase aeration convection but organic decomposition will be concentrated in the bottom layer(Hwang et al., 2015) (Hwang et al., 2002). Continuous addition of waste also affects the quality of compost from kitchen waste (Liu & Price, 2011). An individual composter model with 4 compartments (feeding, compost process, compost discharge, and leachate discharge) equipped with an automatic stirrer has also been developed (Papadopoulos et al., 2009). From a process perspective, a continuous thermophilic composting (CTC) process has been developed which has been proven to speed up the composting process (Xiao et al., 2009) (Elango et al., 2009) (Waqas et al., 2018). Apart from speeding up the composting process, CTCs have also been proven to reduce pathogenic bacteria, integrons and genera that are resistant to antibiotics(Qian et al., 2016), and produce profitable fertilizer (Waqas et al., 2018). Various benefits of CTC occur due to changes in bacterial and fungal communities in the composting process in CTC (Xiao et al., 2009) (Suler & Finstein, 1977). One study showed results with CTC after composting for 14, 16 and 18 days, mature compost was obtained with uniform quality and better than conventional composting for 28 days (Xiao et al., 2009). According to more studies, kitchen and food waste can be thermophilically composted in four days using air input, bacterial seeding, and a stirrer. During this time, temperatures between 50 and 60 degrees Celsius are reached between the eighth and twelfth and fifty and sixty-fifth hours (Chang et al., 2006). Research on forced aeration in a composter showed that for a composter size of 1.05 liters, thermophilic composting occurred at an air rate of 0.05-0.1 liters/minute, while if an air rate was used at 0.2-0.4 liters/minute will result in the process running at mesophilic temperatures (Lu et al., 2001). Meanwhile, for a composter volume of 12 liters, an air rate of 60 liters/minute is used (Suler & Finstein, 1977). This research aims to measure the optimum amount of fresh air flow and the optimum mixing frequency in terms of the parameters of temperature, humidity and pH of the composting process at CTC, and to see their effect on the quality of the compost produced.

Research Methodology

This research was carried out using the CTC machine as in the following picture. The CTC is equipped with a waste chopper at the upper part of the machine. The heater will be set at a temperature of 60°C. The stirring frequency can be set according to needs. There is an air hole (10 cm) with a cover at the bottom. This air hole is made to enter fresh air from outside which is sucked in and flows through the heater and enters the composting room as hot air.

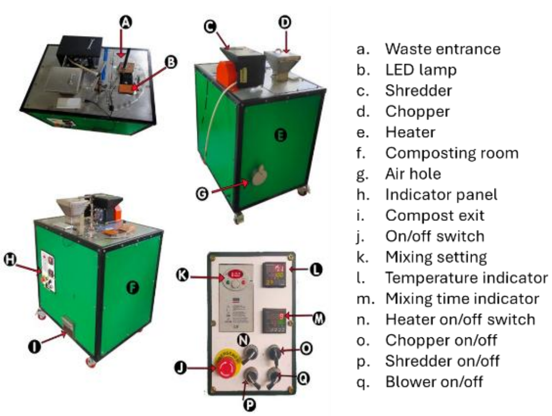


Figure 1. Continous Thermophilic Composting Machine (Patent registration)

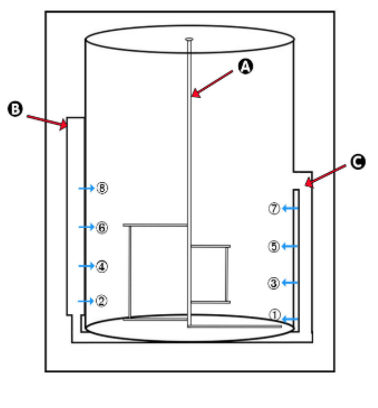


Figure 2. The inside of the composter and the placement of the thermocouple

There are 3 activities in this research, as follows:

1. Modification of the Continuous Thermophilic Composter machine which is equipped with a temperature microcontroller, air holes and stirring automation connected to an Arduino for real time temperature measurement. Measurements are set to be carried out every 30 minutes.
2. The air hole openings are adjusted to determine the ideal air flow. The experiment was carried out with 3 variations of air hole openings with 1 variation of the same stirring frequency. Process combination:
   a. Variation 1: closed air hole with stirring frequency once a day
   b. Variation 2: half open air hole with stirring frequency once a day
   c. Variation 3: fully open air hole with stirring frequency once a day

   Each variation is carried out for 8 days. At the beginning of the process, 2 kg of mature compost is added as a starter. Every day, the same composition of organic waste is added after each kilogram of waste is treated with 8 milliliters of effective microorganism solution (EM4). Waste is chopped before entering the composting room. Stirring is carried out for 1 minute after the waste enters the composting room at a speed of 10 rpm. The frequency of stirring is adjusted to the research plan. Several parameters are measured during the composting process:
   a. Physical parameters: temperature in various height, humidity, oxygen content, and pH are measured every day.
   b. Chemical examination of organic waste and mature compost (starter) at the beginning of the process, an compost at the end of the process

   This activity will result in the best arrangement of air holes which will provide the best composting process which is indicated by (1) thermophilic temperature that is reached more quickly and lasts longer and (2) the results of examination of the compost chemical parameters that meet the requirements of SNI 19-7030-2004 concerning Compost Specifications from Domestic Organic Waste .
3. Determining the optimum stirring frequency. The aim of increasing the frequency of stirring is to increase oxygen levels in the pile and see the effect on temperature and compost yield. The experiment was carried out with 3 variations of stirring frequency with the best air hole settings (results of activity 2). Stirring is done for 1 minute for 10 rounds. Combination of processes carried out:
   a. Variation 1: stirring frequency 1 time a day with optimum air hole opening
   b. Variation 2: stirring frequency 2 times a day with optimum air hole opening
   c. Variation 3: stirring frequency 6 times in 12 hours with optimum air hole opening.

   The procedures followed and the parameters measured are the same as in activity 2. And this activity will produce the best stirring frequency at the best air hole openings.

Results and Discussion

Chemical characteristic of waste and starter compost

The results of the chemical examination of fresh waste and mature compost (starter) are shown in the following table.

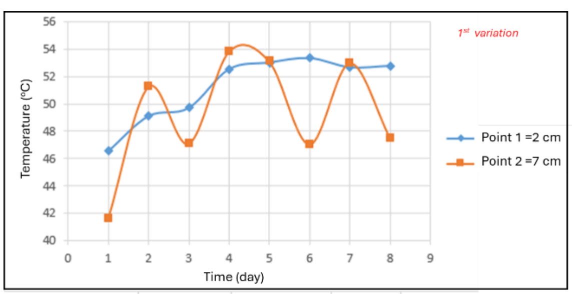
Table 1. Chemical characteristics of waste and starter

Parameter	Metode	Unit	Raw waste	Starter
Water Content	ASTM D2216-80	%WW	90.07	37.45
Volatile	ASTM D3175–07	% DW	58.21	32.11
Phosphate	ASTM D2216-80	mg/kg	2,467	812.4
C-organic	SMEWW-5220-B	% DW	45.23	40.89
NTK	SMEWW-4500-N org + B	% DW	1.12	1.45
C/N ratio			40.23	28.2

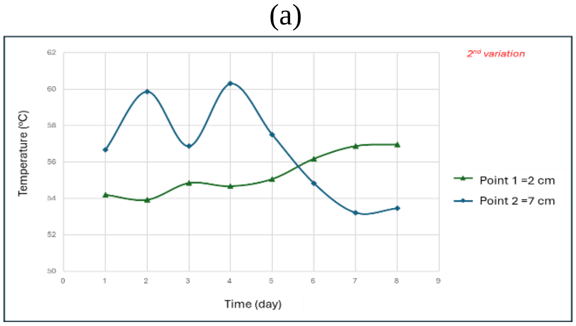
The water content in waste is higher than the optimum water content in waste that is suitable for composting. If the water content is more than 70%, it needs to be turned every day so that the water evaporates and there is sufficient oxygen in the pile (Damanhuri, 2008). Concurrently, the waste's C/N ratio value is larger than the typical 30:1 ratio of waste that is suitable for composting (Sahwan, 2016). The addition of mature compost as a starter, apart from adding microorganisms, also reduces C concentration and improves the C/N ratio of waste.

Airflow optimization

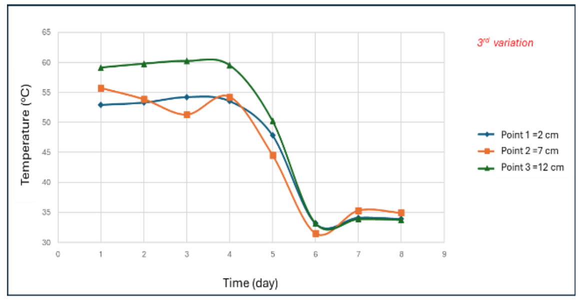
The results of average temperature per day observations are shown in the Figures 3.



(a)



(b)

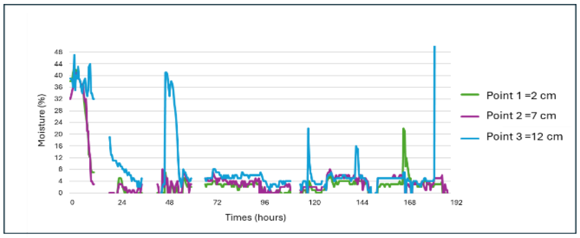


(c)

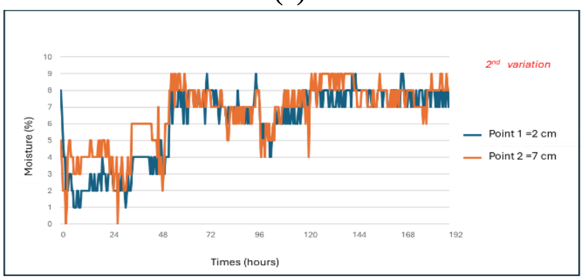
Figure 3. The average temperature of the composting process on air flow optimization stage (a) 1st variation of air flow optimization stage research, (b) 2nd variation of air flow optimization stage research, (c) 3rd variation of air flow optimization stage research

In 1st variation, the compost temperature at point 1 increases and reaches an optimum temperature of 50-60ºC. Point 2 is at the top of the pile, the stirring process often makes the height of the pile wavy unevenly, so that point 2 does not consistently measure the temperature of the pile The temperature in the aerobic composting process should be able to reach a thermophilic state ranging between 60°C-70°C so that weed seeds and pathogenic bacteria die. The same condition occurs in the second variation, where the temperature of point 2 is not consistent because the compost pile has not completely covered point 2. Point 1 consistently shows the temperature moving up to the thermophilic phase. In the third variation, point 3 directly measures the temperature of the air entering from the air hole, point 1 and point 2 are consistently in the thermophilic phase, but lower than second variation. In the third variation, more fresh air from outside enters than in the second variation, but without the entry of fresh air (in the first variation) the oxygen level in the composting room can decrease and the oxygen needs of microorganisms become limited. On the fifth day of third variation, the heater was turned off to see the ability of the process to maintain the thermophilic phase, but the temperature dropped towards the mesophilic phase, and began to rise on days 7 and 8. The highest and relatively constant temperature of the thermophilic phase was obtained in the second variation.

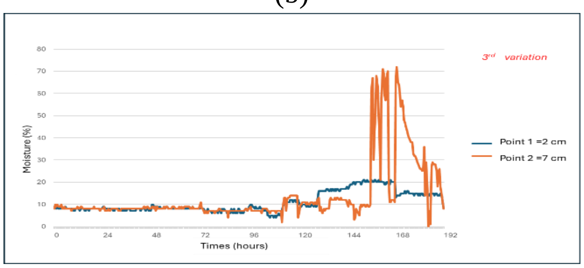
The results of composting moisture measurements are shown in the following figure.



(a)



(b)

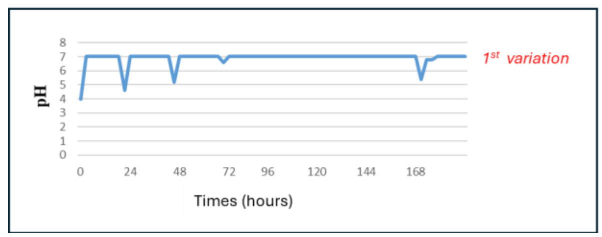


(c)

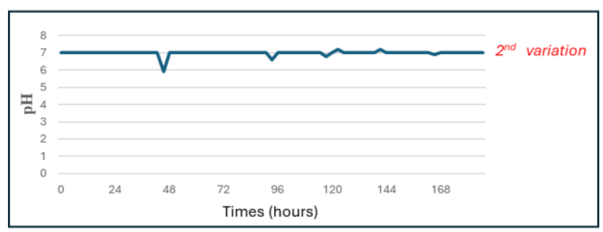
Figure 4. Composting moisture on air flow optimization stage, (a) 1st variation of air flow optimization stage research, (b) 2nd variation of air flow optimization stage research, (c) 3rd variation of air flow optimization stage research.

At the beginning of each day, there is an increase in humidity due to the presence of new waste. Within 24 hours there was a significant decrease to below 10%. In the second variation, the measured moisture is consistently below 10%. There was a slight increase when new waste came in at the start of the day. In the third variation, the increase in moisture occurs significantly when the heater is turned off because new waste with high water content enters the compost mixture, thereby reducing the temperature and increasing the moisture of mixed waste. The moisture of the compost material affects the microorganisms involved in composting (Suwatanti & Widiyaningrum, 2017). The optimum moisture for aerobic composting is 40%-60%. If it is too low (12%-40%), the life of microorganisms will be disturbed because microorganisms really need water as their habitat. If the water content is small then its living space will be limited so it will not be able to reproduce itself properly. Moisture values of less than 12% make the composting process not work (Sahwan et al., 2011).

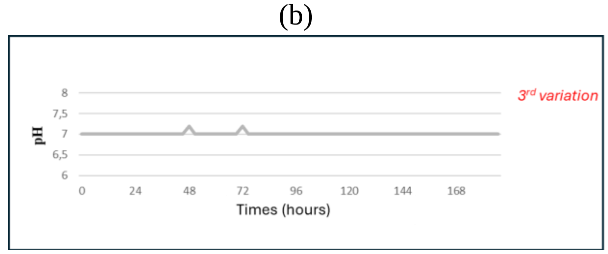
pH measurements are carried out using a manual sensor without the aid of a data acquisition system. The following is a graph of pH measurements.



(a)



(b)



(c)

Figure 5. pH average on air flow optimization stage (a) 1st variation of air flow optimization stage research, (b) 2nd variation of air flow optimization stage research, (c) 3rd variation of air flow optimization stage research.

pH affects the availability of nutrients needed by microorganisms and influences all microorganism activities. The optimum pH condition for the life of microorganisms is between 6 and 8 (Sahwan et al., 2011). pH measurements for all variations were within the normal range.

The results of the chemical analysis of the compost are shown in the following table. The SNI used is SNI 19-7030-2004 concerning Compost Specifications from Domestic Organic Waste.

Table 2. Chemical characteristics of compost on air flow optimization stage research.

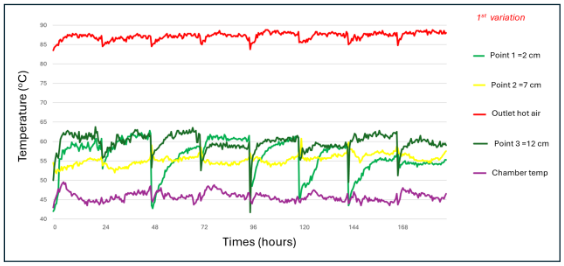
Parameter	Methods	Unit	SNI		Result		
			min	max	1st var	2nd var	3rd var
Water content	ASTM D2216-80	%ww	-	50	37.45	11.12	13.87
Colour			-	blackish	soil colour	soil colour	soil colour
Smell			-	smelly	soil smell	soil smell	soil smell
Volatile content	ASTM D3175-07	%dw			27.45	21.65	29.60
Phosphor	ASTM D2116-80	mg/kg	0.1	-	672.55	751.43	542.21
C-organic	SMEWW-5220-B	%dw	9.8	32	40.89	32.75	28.09
NTK	SMEWW-4500-Norg*B	%dw	0.4		1.39	1.88	1.65
C/N ratio			10	20	29.41	17.42	17.02

Based on air flow optimization research with three variations, it can be seen that in terms of temperature attainment, the second variation has a relatively stable temperature in the thermophilic phase. Based on the quality of the compost, especially the C-organic and C/N ratio parameters, the second and third variations have met the criteria. While all variation have Nitrogen Total Kjeldahl (NTK) value also met the criteria. The decrease in the C/N ratio is caused by a decrease in the C-Organic content which is used as an energy source and to compose the cellular material of microorganisms by producing CO_2 and methane and other volatile materials, while N-Total in compost is a nutrient used by microorganisms in their development. High N-Total levels cause the C/N ratio to be lower, while low N-Total levels cause the C/N ratio to be higher (Asri et al., 2017). Thus, for the stage of determining the stirring frequency optimization, the best results from the air flow optimization stage will be used, which is second variation with half-open holes.

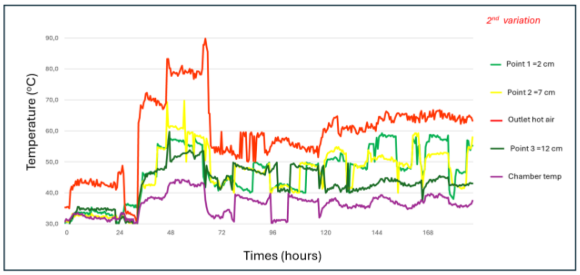
Optimization of stirring frequency

At the stage of determining the optimal stirring frequency, it is carried out with the air hole half open. The research was carried out following previous research (airflow optimization) to observe the composting process at a higher pile height and away from the hot air inlet located at the bottom of the composting chamber. Temperature measurements at the hot air outlet hole and the temperature of the composting chamber at the top were also carried out. The results of temperature per hour observations are shown in Figure 5 below.

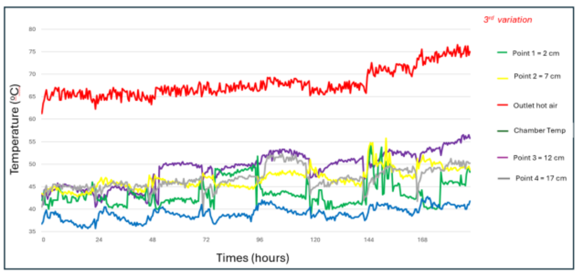
In Figure 5 it can be seen that the temperature of the hot air entering the composting room is above 60ºC, except in the second variation there is a problem with the installed thermocouple so that the reading regularly drops. The temperature at the top of the composting chamber ranges from 30-50ºC. The temperature of the composting process (at points 1, 2, 3, 4) in the first variation is around 55-65ºC, in the second variation it is around 40-60ºC, and in the third variation it is around 40-55ºC. The lower temperatures achieved in the second and third variations are because stirring is done more frequently. It can be seen that there is a decrease in temperature every 12 hours in the second variation and every 2 hours in the first 12 hours in the third variation. In this case, the first variation provides more thermophilic phase stability, although the second variation is not significantly different. Thermophilic conditions are achieved in all variations, and it is hoped that the organic decomposition rate will be faster (Schulze, 1962).



(a)



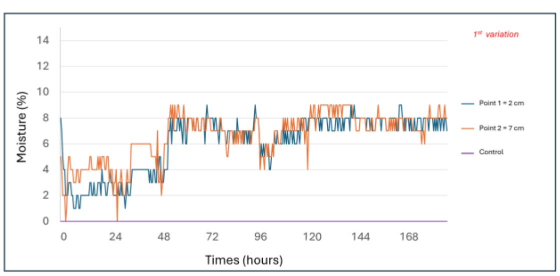
(b)



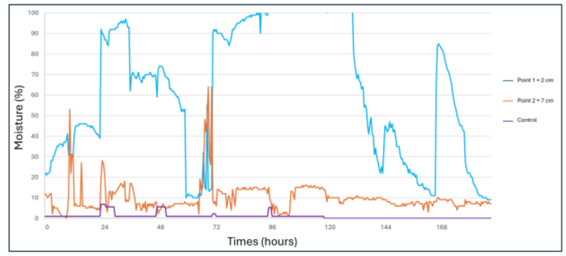
(c)

Figure 6. Temperature in composting proses on stirring frequency optimization stage, (a) 1st variation of stirring frequency optimization stage research, (b) 2nd variation of stirring frequency optimization stage research, (c) 3rd variation of stirring frequency optimization stage research

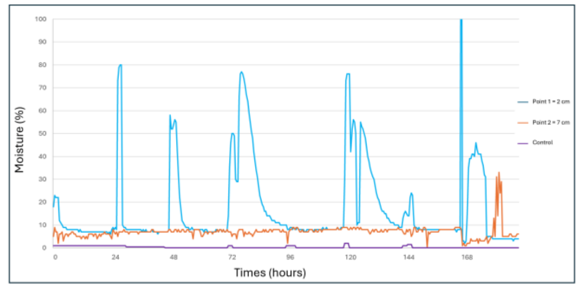
Moisture measurements were carried out at 2 points and 1 as a control. The measurement results are shown in Figure 7.



(a)



(b)

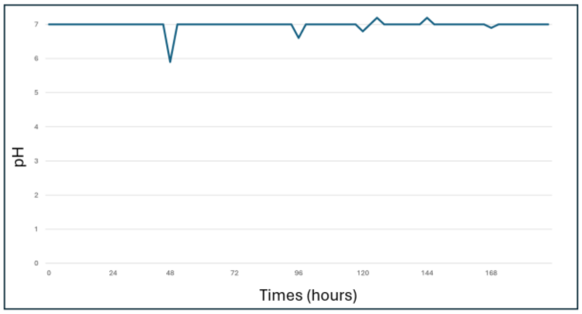


(c)

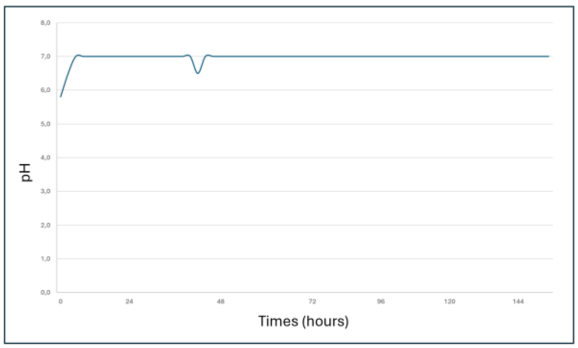
Figure 7. Moisture in composting proses on stirring frekuency optimization stage, (a) 1st variation of stirring frequency optimization stage research, (b) 2nd variation of stirring frequency optimization stage research, (c) 3rd variation of stirring frequency optimization stage research.

The humidity of the composting process increases when fresh waste enters, reaching 90% in the second variation. However, it quickly decreased due to the heating process carried out. In the first variation, humidity increases slightly as more fresh waste is introduced. Meanwhile in the second and third variations there was an error in reading point 2, while point 1 in the second variation also experienced an error. Basically the composting process runs in low humidity conditions. It is feared that microorganisms cannot grow at humidity less than 12% (Sahwan et al., 2011).

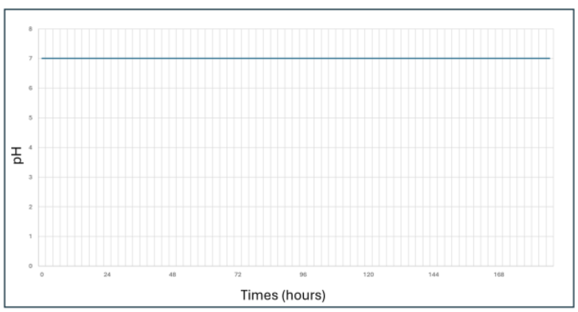
During the composting process, pH measurements are carried out at one point manually, measuring once every day. The results of the pH measurement are shown in Figure 7 below. The pH was in the neutral range in all research variations. Microorganisms can only survive in pH values between 6 and 8 (Sahwan et al., 2011).



(a)



(b)



(c)

Figure 8. pH in composting proses on stirring frequency optimization stage, (a) 1st variation of stirring frequency optimization stage research, (b) 2nd variation of stirring frequency optimization stage research, (c) 3rd variation of stirring frequency optimization stage research

The results of the chemical analysis of the compost are shown in Table 3. The SNI used is SNI 19-7030-2004. Based on water content, all variations meet SNI requirements, with a color and smell that resembles soil. Based on C-organic content, only the first variation slightly exceeds the provisions, while all NTK values meet SNI.

Table 3. Chemical characteristics of compost on stirring frequency optimization stage research

Parameter	Methods	Unit	SNI		Result		
			min	max	1st var	2nd var	3rd var
Water content	ASTM D2216-80	%ww	-	50	11.12	15.77	13.99
Colour			-	blackish	blackish brown	blackish brown	blackish brown
Smell			-	smelly	soil smell	soil smell	soil smell
Phosphor	ASTM D2116-80	mg/kg	0.1	-	239.81	134.71	160
C-organic	SMEWW-5220-B	%dw	9.8	32	32.75	25.11	29.9
NTK	SMEWW-4500-Norg*B	%dw	0.4		1.88	1.39	1.21
C/N ratio			10	20	17.42	18.06	24.71

Regarding the C/N ratio value, only the third variation does not meet the SNI requirements. Based on the temperature achieved, the first and second variations are more consistent in the thermophilic phase. Based on all considerations and analysis, the frequency of stirring twice a day is considered to provide better compost results. Stirring is done to increase oxygen levels in the waste pile and even out the waste mixture. The C/N ratio contained in compost describes the maturity level of the compost, the higher the C/N ratio means the compost has not decomposed completely or in other words is not yet mature (Surtinah, 2013).

Conclusions

In this research on continuous thermophilic composting, there are several findings, i.e.:

1. In the aerobic composting process using CTC, fresh air is required to increase oxygen levels, but the air flow rate must be regulated so that the fresh air flow does not reduce the temperature in the composting room. Setting the vent openings half open gives better results than closed and fully open.
2. The aerobic composting process using CTC also requires stirring, especially to evenly distribute the components in the waste mixture and increase oxygen levels so that

aerobic composting can occur properly. Stirring must be regulated only once or twice a day, because stirring too often will decrease the temperature and quality of the compost.

References

Asri, D., Ratna, P., Samudro, G., & Sumiyati, S. (2017). Pengaruh Kadar Air Terhadap Proses Pengomposan Sampah Organik dengan Metode Takakura. In *Jurnal Teknik Mesin (JTM)*, *6*(2), 124-128.

Chang, J. I., Tsai, J. J., & Wu, K. H. (2006). Thermophilic composting of food waste. *Bioresource Technology*, *97*(1), 116-122. https://doi.org/10.1016/j.biortech.2005.02.013

Damanhuri, E. (2006). Some principal issues on municipal solid waste management in Indonesia. *1st Expert Meeting on Waste Management in Asia - Pacific Islands*, Oct 27 - 29, Tokyo, 1-6

Damanhuri, E. (2008). A Future prospect of municipal solid waste management in Indonesia. Keynote Lecture in *the 5th Asian-Pacific Landfill Symposium in Sapporo, Japan*, Nov 22-24, 1-14

Damanhuri, E., Handoko, W., & Padmi, T. (2014). Municipal solid waste management in Indonesia. *Municipal Solid Waste in Asia and the Pacific Islands*, 139-155 https://doi.org/10.1007/978-981-4451-73-4_8

Elango, D., Thinakaran, N., Panneerselvam, P., & Sivanesan, S. (2009). Thermophilic composting of municipal solid waste. *Applied Energy, 86*(5), 663-668. https://doi.org/10.1016/j.apenergy.2008.06.009

Gill, S. S., Jana, A. M., & Shrivastav, A. (2014). Aerobic Bacterial Degradation Of Kitchen Waste : A Review. *Journal of Microbiology, Biotechnology and Food Sciences*, *3*(6), 477483.

Hwang, E. J., Shin, H. S., & Tay, J. H. (2002). Continuous feed, on-site composting of kitchen garbage. *Waste Management and Research*, *20*(2), 119-126. https://doi.org/10.1177/0734242X0202000203

Liu, K., & Price, G. W. (2011). Bioresource Technology Evaluation of three composting systems for the management of spent coffee grounds. *Bioresource Technology*, *102*(17), 7966–7974. https://doi.org/10.1016/j.biortech.2011.05.073

Lu, S. G., Imai, T., Li, H. F., Ukita, M., Sekine, M., & Higuchi, T. (2001). Effect of enforced aeration on in-vessel food waste composting. *Environmental Technology*, *22*(10), 1177-1182. https://doi.org/10.1080/09593332208618200

Mulyatna, L., Rochaeni, A., Saputra, R., Yogi, B., & Fiqri, I. (2022). Effect of Variations in the Pretreatment of Organic Waste on The Growth of Black Soldier Flies (BSF) Larval. *Journal of Community Based Environmental Engineering and Management*, *6*(2), 99–110. https://doi.org/10.23969/jcbeem.v6i2.6161

Papadopoulos, A. E., Stylianou, M. A., Michalopoulos, C. P., Moustakas, K. G., Hapeshis, K. M., Vogiatzidaki, E. E. I., & Loizidou, M. D. (2009). Performance of a new household composter during in-home testing. *Waste Management*, *29*(1), 204–213. https://doi.org/10.1016/j.wasman.2008.03.016

Qian, X., Sun, W., Gu, J., Wang, X. J., Zhang, Y. J., Duan, M. L., Li, H. C., & Zhang, R. R. (2016). Reducing antibiotic resistance genes, integrons, and pathogens in dairy manure by continuous thermophilic composting. *Bioresource Technology, 220*, 425-432. https://doi.org/10.1016/j.biortech.2016.08.101

Rochaeni, A., Ismaria, R., & Fanira, S. (2021). Analysis of kitchen organic waste for processing using Black Soldier Flies in Kecamatan Cibiru, Bandung, West Java. *IOP Conference Series: Earth and Environmental Science, 737*, 012073.

https://doi.org/10.1088/1755-1315/737/1/012073

Rochaeni, A., Mulyatna, L., Ariantara, B., Fathul, M., & Sagrim, W. M. (2021a). Continuous thermophilic composting process using heating lamps controlled by a microcontroller. *IOP Conference Series: Earth and Environmental Science*, *802*, 012052. https://doi.org/10.1088/1755-1315/802/1/012052

Sahwan, F. L. (2016). Analisis Proses Komposting Pada Pengelolaan Sampah Berbasis Masyarakat Skala Kawasan (Studi Kasus Di Kota Depok). *Jurnal Teknologi Lingkungan*, *13*(3), 253-260. https://doi.org/10.29122/jtl.v13i3.1394

Sahwan, F. L., Wahyono, S., & Suryanto, F. (2011). Kualitas Kompos Sampah Rumah Tangga yang Dibuat dengan Menggunakan ”Komposter” Aerobik. *Jurnal Teknologi Lingkungan*, *12*(3), 233–240.

Schulze, K. L. (1962). Continuous thermophilic composting. *Applied Microbiology*, *10*(2), 108-122. https://doi.org/10.1128/aem.10.2.108-122.1962

Suler, D. J., & Finstein, M. S. (1977). Effect of temperature, aeration, and moisture on CO_2 formation in bench scale, continuously thermophilic composting of solid waste. *Applied and Environmental Microbiology*, *33*(2), 345-350. https://doi.org/10.1128/aem.33.2.345-350.1977

Surtinah. (2013). Pengujian Kandungan Unsur Hara Dalam Kompos Yang Berasal Dari Serasah Tanaman Jagung Manis (Zea mays saccharata), *Jurnal Ilmiah Pertanian*, 11(1), 11-17.

Suwatanti, E., & Widiyaningrum, P. (2017). Pemanfaatan MOL Limbah Sayur pada Proses Pembuatan Kompos. *Jurnal MIPA*, *40*(1), 1–6. http://journal.unnes.ac.id/nju/index.php/JM

Waqas, M., Almeelbi, T., & Nizami, A. S. (2018). Resource recovery of food waste through continuous thermophilic in-vessel composting. *Environmental Science and Pollution Research*, *25*, 5212-5222. https://doi.org/10.1007/s11356-017-9358-x

Xiao, Y., Zeng, G. M., Yang, Z. H., Shi, W. J., Huang, C., Fan, C. Z., & Xu, Z. Y. (2009). Continuous thermophilic composting (CTC) for rapid biodegradation and maturation of organic municipal solid waste. *Bioresource Technology*, *100*(2), 4807-4813. https://doi.org/10.1016/j.biortech.2009.05.013

Yustiani, Y. M., Rochaeni, A., & Aulia, E. (2019). Konsep Pengelolaan Sampah Di Desa Babakan Kabupaten Bandung. *EnviroScienteae*, *15*(1), 121-126. https://doi.org/10.20527/es.v15i1.6332

Yustiani, Y.M. & Abror, D.F. (2019). Pengelolaan Bank Sampah Unit dala Pengelolaan Sampah Perkotaan, *Jurnalis*, *2*(2), 82-89.