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# Developing A Thermal-Composting System for Recycling Household Biodegradable Solid Waste

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In Vietnam, more than 50 % of municipal solid waste is biodegradable solid waste, in which food waste, including kitchen waste and the leftover, is the main component. The mixing of domestic waste in collection and treatment has brought significant environmental consequences. The waste separation policy towards strategic goals in waste management has posed many challenges for the locality in implementation. This study aims to develop a pilot of the thermal composting system to optimize the household organic waste composting process. The pilot has a volume of 12 L, a bottom heating system, and a temperature measurement and monitoring system. The system operates on a batch mechanism; the first batch is started with the addition of sawdust substrate at a rate of 1/3 of the volume of food waste. From the 2nd batch onwards, 1/3 of the compost product is kept in the system to mix with the raw materials. The heating system only provides a temperature of 40 °C during the first 2 d of the treatment. The results show that the thermal-composting system is activated quickly in the first 2 d, and the treatment process is highly effective in the next 3 d with temperatures ranging from 60 to 70 °C. The pile volume decreased rapidly by 50 % within 5 d of treatment and stabilized gradually in the last 2 d. After 7 d of treatment, the compost has a temperature of about 40 °C with a moisture content of 31.3 %. Compost products have high organic content (57.8 %), low nutrient content, and heavy metal content below the allowable threshold in microbial organic fertilizers standards (TCVN 7185:2002). Efficiency in home composting with a shortened retention time of 7 d, simple operation, and friendly compost quality are the outstanding results of this applied research. This study provides a practical product for implementing new waste management regulations in Vietnam. It also awakens the potential to promote the municipal organic solid waste recycling system, contributing to reducing the waste to landfills and mitigating greenhouse gas emissions towards a waste circular economy.

## 1. Introduction

Kitchen waste which includes leftover and food waste from cooking accounted for the highest proportion of the total municipal solid waste (MSW). In developed countries, the ratio of organic waste is not too high compared to other components. In Seoul, food waste accounted for 12.37 % of the total MSW, due to the policy of banning food waste burying activities since 2005, and the promotion of organic waste separation reduction since 2010 (Thi et al., 2015). In Tokyo, the effective implementation of waste segregation at source, 3Rs campaigns, and high-tech waste treatment methods had increased organic waste recycling, even though the proportion of organic waste is not low (Liu et al., 2016). This is the opposite in developing countries. In China, kitchen waste had a steadily increasing rate, and reached 30 million t in 2016, making up 50 – 60 % of the total MSW (Wang et al., 2018). According to the national report of MSW management, about 50 to 80 % of the total waste in the landfill are organic waste (MONRE, 2020).
Composting and anaerobic digestion are the two effective organic waste treatment methods, with zero or least energy consumption, simple odor emission and leachate management process, bring benefits from the output of fertilizer (Song Toan et al., 2021), and more importantly, less pollution than incineration or landfilling (Song Toan et al., 2022). In high-income countries, large-scale composting systems are more common while middle-

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and low-income countries preferred small-scale composting, or landfilling (Sabki Mirza Hussein et al., 2018). The temperature of composting pile usually ranged from 40 to 55 °C, which is lower than the heat resistance threshold of pathogens or weeds (Stani, 2016), and the process of the bio-decomposition is rather slow, from 3 weeks (Song Toan et al., 2021) up to 40 d (Elango et al., 2009). With the high urbanization and modernization rate, the application of these methods in the cities of Vietnam is impossible.

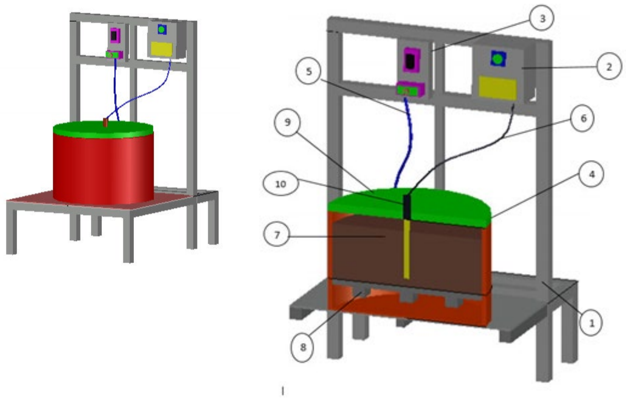
Song Toan et al., (2022) developed a home-composting system with a capacity of 10 kg/d to recycle kitchen waste in accommodations, restaurants, or primary schools. This study revealed that kitchen waste waste has been completely treated in 3 weeks by in-vessel technology composting system. Heat-composting is a new method that uses the high temperature generated from a heated reactor in order to increase the initial temperature, cause the thermal phase to come faster as well as increase the efficiency of the bio-degradation process, reducing the period of composting to less than a week (Ahn et al., 2007). In addition, with the highest temperature value of 80 °C and the average fluctuation at 70 °C, most harmful microorganisms will be eliminated. In China, a large-scale heat-composting treatment plant had been built in Jaozuo, 2013, which can treat more than 40 t of cattle manure, with minimized odor emission and leachate (Wang and Wu, 2021). Compared with commercial composting systems, Cui et al., 2019 indicated that with a maximum temperature of 88.3 °C, heat composting has lower nutrient loss. Simultaneously, heat composting also has higher fertilizer quality than traditional composting (Yu et al., 2018).

Composting is simple technology however implementation of composting in waste reduction at source is very difficult in Vietnam and developing countries because of many barriers such as odor, leachate, and long-duration time. In the context of the confusion of the solid waste management system, the new national environmental protection law, which was enacted and took effect on January 1, 2022, requires mandatory waste separation at source and law of the tipping fee as “Pay as you throw”. At the moment, heat composting is an essential and effective solution for law enforcement, especially for households. This study aims to develop a thermal-composting system to recycle municipal biodegradable waste at sources in Vietnam. The benefits of home composting are also assessed in micro- and macro-views to contribute to the decision-making process of waste management practice in Vietnam.

## 2. Methodology

### 2.1 Establishing a thermal-composting (TCOM-HOME) system

TCOM-HOME system was established for recycling household kitchen waste. This composter was developed based on thermal-composting technology with a capacity of 12 L (equivalent to 2 kg/d). Figure 1 illustrates the structure of the TCOM-HOME system. The main part is a sealed reactor with a heating system at the bottom, which has the heating capacity by 80 °C. The operating volume of composting occupies about 80 % of the reactor’s volume with a temperature sensor located in the core of the pile, connected to the data board via electrical wiring. The capacity of the heating system can be adjusted.



(1) – Shelf
(2) – Data board
(3) – Heat controler
(4) – Reactor
(5) & (6) – Electric lines
(7) – Composting material
(8) – Heating system
(9) – System cover
(10) – Heating sensor

*Figure 1: Thermal-composting (TCOM_HOME) system*

### 2.2 Operating TCOM-HOME system

There are three identical thermal-composting systems are piloted in three same size households. The TCOM-HOME system waste is operated under the supplied heating system. Biodegradable waste from households was cut to the size of 1 cm and mixed with sawdust with a ratio of 3:1, then put into the reactor. 10 mL of effective microorganisms (EM), which is produced by URENCO was added to the TCOM-HOME system (15 L) for the first batch. The C/N and moisture content of the input mixing materials in three systems range from 30 to 40, and 65 to 73 °C, respectively. The heat was supplied to the TCOM-HOME and maintained at 40 °C for the two first days of the composting process. The material was turned once a day and aerated in 1 min. The retention time is 7 d. From the second batch, 30 % of compost (by volume) is retained in the reactor to be mixed with new food waste. Only 3 mL of EM is added to speed up the decomposition process.

### 2.3 Compost quality measurement

The moisture content and temperature were measured to assess the composting process. After 7 d, the quality of the compost product was identified and compared with organic fertilizer standards through the following 11 parameters.

*Table 1: Methods of compost quality measurement*

| No | Parameter | Unit | Method |
|---|---|---|---|
| 1 | pH | - | TCVN 5979:2007 |
| 2 | Moisture | % | TCVN 10788:2015 |
| 3 | Total N | % | TCVN 8557:2010 |
| 4 | Total P | % | TCVN 8559:2010 |
| 5 | Total K | % | TCVN 8560:2018 |
| 6 | Organic | % | TCVN 9294:2012 |
| 7 | Total Cr (dry sample) | mg/kg | TCVN 10674:2015 |
| 8 | Total Ni (dry sample) | mg/kg | TCVN 10675:2015 |
| 9 | Total Pb (dry sample) | mg/kg | TCVN 9290:2018 |
| 10 | Total Cd (dry sample) | mg/kg | TCVN 9291:2018 |
| 11 | Total Hg (dry sample) | mg/kg | TCVN 10665:2015 |

## 3. Results and discussions

### 3.1 Temperature fluctuations during the composting process

Figure 2 indicates that the material's temperature in the reactor's center can be reached 60 to 70 °C after 1 d and continue to be maintained until the fifth day. The heat was just supplied in the first 2 d of the composting process. The compost pile's temperature decreased on the sixth day, signaling that the decomposition process had entered the final stage and began to stabilize. There is a slight difference in the temperature of composting process in three households (S1, S2, and S3). This may be explained by the food waste characteristics and the operation behavior.

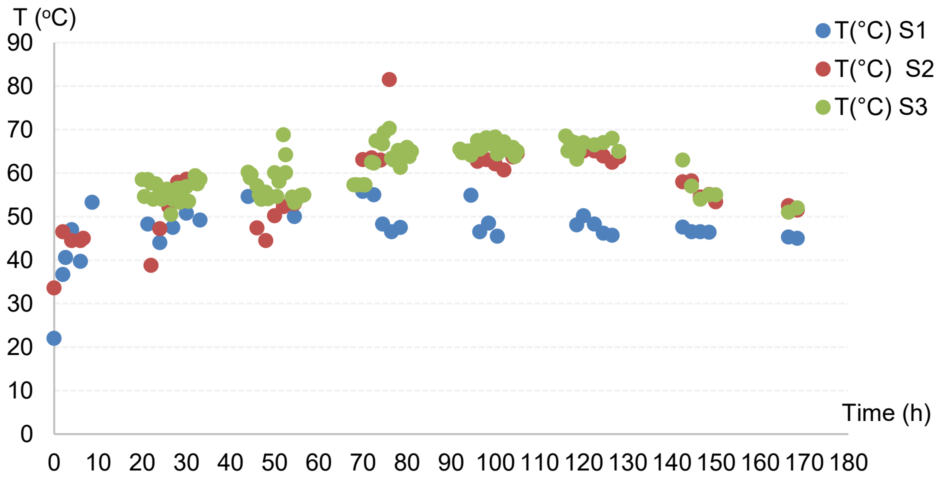



*Figure 2: The distribution of temperature value in TCOM-HOME*

The daily mixing time (about 5 minutes) may lead to a temperature leak. The temperature fluctuation before and after mixing is about 3 to 5 °C. The temperature in the core of the compost pile quickly increased to the initial value after mixing within about 30 minutes. The value and fluctuation of temperature during the composting process are important, and can significantly affect the treatment performance of thermal composting. Especially, for a small composting system (household scale), the balance between mixing time, aeration, and heat preservation should be optimized. This is a basis for testing this pilot with a continuous composting process, whereby, organic waste will be added once a day for 5 min of the mixing phase.

### 3.2 The changes in moisture content during the composting process

The moisture content of the raw materials (kitchen waste and sawdust) ranges from 65 to 70 %. Figure 3 shows that the dehydration and moisture loss decreased during the thermal composting with daily mixing. The moisture content was reduced by 3 - 5 %/d and reached a suitable value of 30 % for the product after 7 d without any water addition during the composting process. There is no significant differences between the moisture content of S1, S2, and S3. The operating procedure of this system shows that it is suitable for wet raw material as kitchen waste in the closed composting system. This is also expected to be ideal for households' daily practice of home composting.

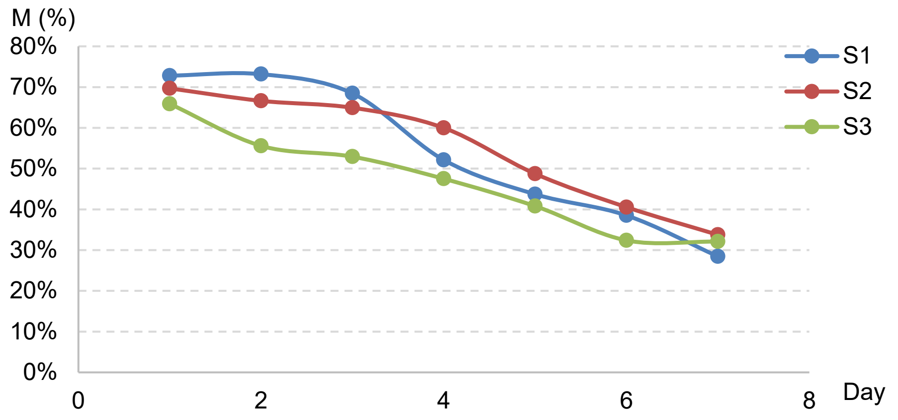



*Figure 3: The changes in moisture content in the TCOM-HOME system*

### 3.3 The mass volume reduction

Figure 4 shows the volume of the composting material in TCOM-HOME system in the first 5 d of the composting process and stabilizes the volume for the remaining 2 d. The rapid decomposition rate under the role of the thermophilic microflora may be the main cause of the decrease in the volume of the compost material. This is closely related to the temperature and moisture content measured during composting. The stability of temperature and the volume of the compost in the last 2 d is a sign of the final period of the decomposition process, the beginning of the stabilization phase of the compost product. The compost volume reduction procedure appears to be the same in the three experiments S1, S2, and S3.

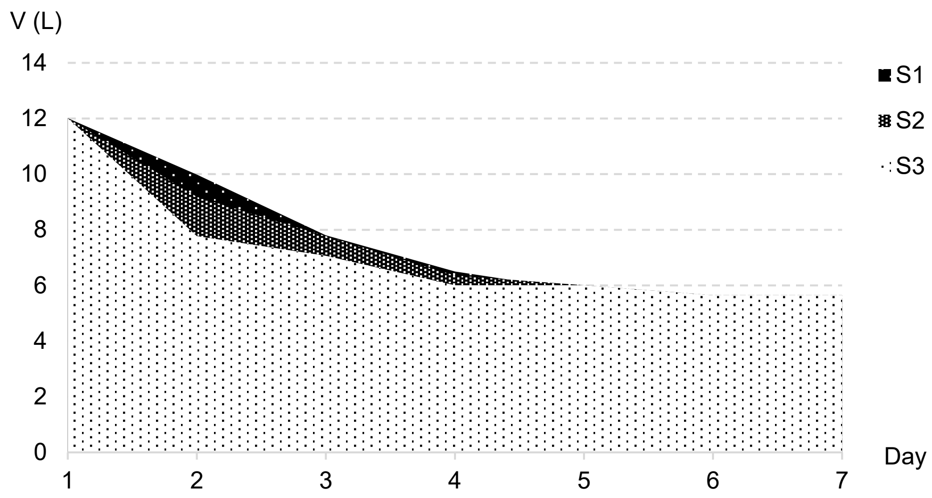



*Figure 4: The volume reduction of the composting pile*

### 3.4 Compost quality

After 7 d of composting, the color of compost is dark brown, and the particle size is small and fine-grained. Compost products were tested to measure the quality and detect hazardous substances present in the compost. Table 2 illustrates that the quality of compost from two composters almost meets the basic quality criteria of Microbial Organic Fertilizer (MOF) as prescribed by Vietnamese Standard TCVN 7185:2002. Namely, the pH and moisture content of compost is satisfactory for packaging, storage, and use. It can be seen that the nutrient content (N, P, and K) is significantly lower than the prescribed MOF's quality. This is explained that the composting process using only the available N and P content in the food waste without any addition.

*Table 2: The quality of compost from TCOM-HOME system*

| No | Parameter | Unit | TCOM-HOME | TCVN 7185:2002 |
|---|---|---|---|---|
| 1 | pH | - | 7.21 | 6.0 – 8.0 |
| 2 | Moisture | % | 31.3 | ≤ 35 |
| 3 | Total N | % | 0.72 | ≥ 2.5 |
| 4 | Total P | % | 0.27 | ≥ 2.5 |
| 5 | Total K | % | 1.09 | ≥ 1.5 |
| 6 | Organic | % | 57.80 | ≥ 22 |
| 7 | Total Cr (dry sample) | mg/kg | 16.55 | ≤ 200 |
| 8 | Total Ni (dry sample) | mg/kg | 3.58 | ≤ 100 |
| 9 | Total Pb (dry sample) | mg/kg | 1.91 | ≤ 200 |
| 10 | Total Cd (dry sample) | mg/kg | 0.62 | ≤ 2.5 |
| 11 | Total Hg (dry sample) | mg/kg | 0.05 | ≤ 2 |

Organic concentration is probably the main ingredient of the compost product with 57.8 % nearly 3 times higher than the quality of the MOF. Nutrients were not added during the composting process, so the content of N, P, and K in the compost is not high. The natural pH and moisture are also quite suitable for the use of compost in cultivation. To storage or packaging is required, the moisture content of the product should be calibrated and controlled to ensure quality.

In Vietnam, harsh climatic conditions and arid soil make agricultural activities to be being difficult and low productivity (Yen et al., 2013). In addition, annual natural disasters are concurrent with the effects of climate change, making the land increasingly fertile, difficult to cultivate, abandoned fields, and metamorphosed cropland. Currently, chemical fertilizers are widely used because of their immediate effect on the crop but leave long-term consequences that are difficult to improve the soil quality. With such a situation, agricultural activities in central Vietnam are increasingly limited; arable land is shrinking, and unemployment and occupation change are increasing, causing many difficulties for society. With the low nutrient and high organic content, this compost product can be widely used for agricultural soil improvement, organic enrichment for degraded soil, and moisture retention for land, contributing to limiting the impact of natural disasters on agriculture.

The use of organic fertilizers for agriculture in developing countries in general and Vietnam, in particular, has also existed for a long time (Atieno et al., 2020). it is increasingly limited by farmers' immediate efficiency requirements. Besides, the production of organic fertilizer from waste does not seem to ensure the quality for farmers to trust. According to the report of the Ministry of Natural Resources and Environment (2019) on Municipal Solid Waste Management, there are 37 composting plants nationwide, but all of them are inefficient. One of the main reasons is that domestic solid waste has not been segregated at source (MONRE, 2020).

In order to improve the municipal waste management system and facilitate the efficient recycling of waste behind, the law on environmental protection (Law N0.72/2020/QH14) was passed by the National Assembly of the Socialist Republic of Vietnam on November 17, 2020, and takes effect from January 1, 2022. Accordingly, solid waste must be classified into three categories: food waste, recyclable waste, and residual waste. The implementation of solid waste separation at source is difficult and faces many challenges, but it must be done step by step. Simultaneously, building a system of facilities and corresponding technical solutions to synchronize with classified solid waste. Home-Composting was proven as an effective solution to implement this waste management reform in Vietnam (Song Toan et al., 2021). Also, a heat-composting model can be developed to be applied and spread widely as a tool for law enforcement, solving environmental problems, and satisfying the needs of society. As a result, the application of TCOM-HOME is expected as a comprehensive solution, meeting requirements from law on environmental protection and existing problems of municipal organic waste management.

## 4. Conclusions

This study focused on developing a thermal-composting model to recycle biodegradable municipal solid waste. A pilot system of thermal-composting was established with some characterizations: (1) The capacity is 12 L; (2) The retention time of treatment is 7 d; (3) The heating temperature reached 40 °C in the first 2 d.
Reducing the retention time is the highlight of the heat-composting system. Besides, the product from the composting process also shows good quality, is environmentally friendly, and can be used for agricultural, forestry, or soil improvement activities.
This study also contributes effective solutions to recycle organic solid waste at source and introduces tools for sorting and recycling food waste. Convenience and suitable capacity enough for one family to recycle food waste for one week/batch are calculated in the design. The development of functions and changing the design towards replicating the product in the hands of users is the future direction of the research team.

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