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# Effect of Passive Aeration on Fed Batch Composting of Organic Waste in Compost Bioreactors

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## Abstract

The objective of this research is to determine the effect of air on the degradation of food waste using compost bioreactors with different passive aeration. The bioreactor was made of 200L PE plastic container. There were 5 bioreactors identified by different ratios of air volume as 0%, 2.3%, 3%, 4.3% and 5.7% of bioreactors volume or 0, 1, 2, 4 and 6 PVC pipes of diameter 1¼”, respectively. The Fed Batch Composting (FBC) method was used, adding for once per a bioreactor at amount 85 kilograms of materials. The experiment was also subdivided into 2 types: bioreactors with microbes (PD2); and those without microbes. Temperature, moisture content, and pH were measured. Compost samples were analyzed for their germination index (GI) and quality, then compared with the Thailand compost standards. The research output showed that the optimum air volume for composting was 4.3% of bioreactor volume, or 4 pipes. The composting time was 9 days with the highest temperature of 58-59 °C and the temperature was held constantly for 18 days. The organic waste decomposition and curing took a total of 30 days, with a GI value between 85% and the quality of the fertilizer output complied with the Thailand compost standard. The main minerals of the compost were N, P and K, which were 1.57%, 0.87% and 0.75%, respectively. There was no statistically significant difference between the outputs generated from the compost with and without addition of PD2.

***Keywords:*** Food waste composting; Passive aeration; Fed batch composting

## 1. Introduction

The amount of solid waste in Thailand has increased from 26.19 million tons per year in 2014, to 27.8 million tons per year in 2018. Community solid waste management is the work task of the Local Administrative Organizations (LAOs), who are responsible for the collection and disposal of garbage. In 2018, there were 5,169 LAOs (representing 66% of the total LAOs) performed collection and disposal task. While, the remaining 2,607 LAOs (34% of the total LAOs), have not yet carried out for garbage disposal, due to budgetary constraints. In these areas, the disposal of waste is a daily burden, so that people must carry out garbage disposal by themselves.

The Thai government has policy on promotion of the people participation for separation of waste at source, with the 3 Rs principle (reduce, reuse, recycle), as well as encouragement of the communities for making compost from organic waste (Pollution Control Department, 2019). The solid waste produced in Thailand consists of 50% organic waste, which includes food, vegetables, debris, fruit, leaves, and carcasses (Srisatit, 2016). Organic waste is co-disposed of with other garbage. Thus, there are various environmental impacts, such as spoilage, foul odor, leachate to contamination of water and other environmental receptors, and creation of breeding sources for insects (flies and cockroaches), rats, etc. In addition, the decomposition of organic waste in anaerobic conditions produce methane, a greenhouse gas that is a major cause of global warming.

Composting is a process that controls the aerobic degradation of organic substances by microorganisms until stable conditions being reached. The product is a black-brown substance, similar to humus, which can be used as a soil conditioner. The addition of air to the compost bioreactors enables the microorganisms to grow sufficiently causing the proper organic degradation. There are two types of aeration: natural (or passive) mechanisms and mechanical aeration. Natural aeration is the easiest method having the lowest operating cost, due to minimal requirement for equipment. Natural air filling methods that are simple to make including air diffusion and convection methods. These simple methods can control air flow by opening and closing air vents in organic waste composting systems (Fernandes *et al*., 1994). Passive air filling methods have to be installed at the bottom of the compost reactors, or under the fertilizer pile, to increase the pressure of convection in the compost reactors, which is caused by the temperature difference between the inner compost layer and air piles outside the composting reactor (Sartaj *et al*., 1997). In contrast, the aerator method requires the installation of an air duct under the compost pile and uses a fan to blow air into the installed pipe and into the compost layer, with control over the air volume (Haug, 1993). Although the aeration by natural means has appeared to be limited, it has been proven to be as effectively as using an aeration machine, and is also cheaper. The principles of passive air filling methods have been suggested by McGarry and Strainforth (1978).

There are many studies demonstrating the use of passive aeration principles for composting (Mathur *et al*., 1990; Zhan *et al*.,1992; Sartaj *et al*.,1997; Patni *et al*., 2001; Karnchanawong and Suriyanon., 2011 and Barrington *et al*., 2003)

Shimaoka *et al*., (2000) discussed the development of a new landfill model in which air is sent through a tube to collect leachate, with a diameter larger than conventional leachate pipes. This resulted in loopholes for air ventilation as well as the leachate drainage. The mechanism of this air filling is convection, due to the difference between the internal temperature and the outside temperature. The degradation of organic matter by aerobic microorganisms produces heat and gas, causing the air pressure to rise and air to move to the top of the reactors and the outside. Inside the garbage pile, there is an empty hole and low air pressure, causing air from the outside to move into the landfill through the leachate collection pipe. This is a semi-aerobic system (Sutthasil *et al*., 2018)

This study has been interested in composting of food waste from households and small urban communities of Roi-Et Province, Northeastern Thailand, applying the principles of semi-aerobic landfill to design a bioreactor using the passive aeration model. The bioreactors will drain from the bottom and have vertical air ventilation pipes of different air volumes. The focus is on reducing costs, by avoiding the use of aerators, stirrers and energy, while improving composting efficiency to be equal to that of forced aeration systems. The suitability of the model for the degradation of food waste, by considering parameters including high temperatures, short composting times, high-quality compost and processes that are environmentally friendly, will be evaluated.

## 2. Materials and methods

### *2.1 Compost bioreactors*

The experimental bioreactor was made of a 200L PE plastic container with 5 patterns for 5 different ratios of ventilation volume. The following components were implemented: (1) 5 ratios of air volume: 0%, 2.3%, 3%, 4.3% and 5.7% of the total bioreactor volume; (2) each bioreactor had a drain at the bottom with 1 pipe , Ø 1¼ ” placed horizontally throughout the width of the bottom. The control reactor (0% ventilation) was designed to prevent air from entering the tank, by installing a U-shaped water trap; (3) at the center of the top cover, there was 1 small opening and closing box with a size of Ø 15 cm. It is made of concrete and used for filling the bioreactor with organic waste, as well as removing samples; (4) every bioreactor had holes drilled on the wall beside the tank to measure temperature, humidity, pH, and for gas content. These holes were Ø 0.5 cm channel and had plugs. There were 3 levels from the bottom of the tank, as follows: upper, middle and lower level, which were 45, 30 and 15 cm height, respectively; (5) every bioreactor was covered with a 3.0 mm thick PE foam insulation layer to control the temperature inside the reactor.

Installation of ventilation pipes in the bioreactors was done at 5 ratios and each ratio was applied to 2 reactors. This provided a total of 10 bioreactors, which were as follows:

(1) The control unit with 0% air volume, with a drain, namely FBC1 and FBC6, as shown in Figure 1(a) and Fig. 2(a);

(2) Experimental units with a volume of 2.3% were equipped with 1 perforated pipe, including FBC2 and FBC7. Figure 1(b);

(3) Experimental units with 3% air volume were equipped with 2 perforated pipes, including FBC3 and FBC8. This was a total of 2 reactors, as shown in Figure 1(c) and Fig. 2(b);

(4) Experimental units with 4.3% air volume were equipped with 4 perforated pipes, including FBC4 and FBC9 . Fig. 1(d);

(5) Experimental units with a volume of 5.7% were equipped with 6 perforated pipes, including FBC5 and FBC10. Fig.1(e).

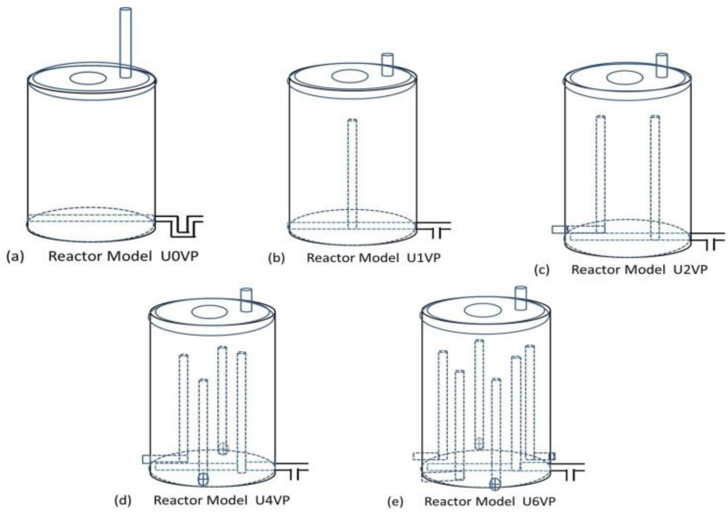


**Figure 1.** All 5 reactors; (a):U0VP, (b):U1VP, (c):U2VP, (d):U4VP and (e): U6VP

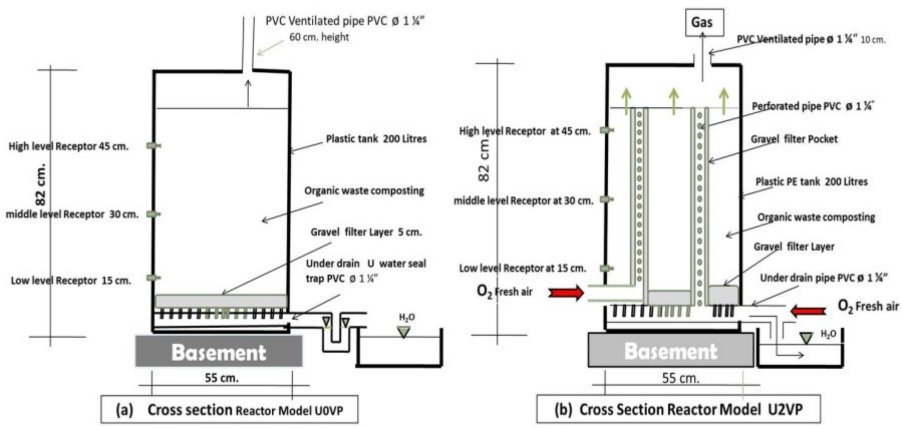


**Figure 2.** Cross section of bioreactor Model; U0VP is a control set and U2VP is an experimental set.

### 2.2 Experiments

#### 2.2.1 Experimental design

The experiment was fully decomposed organic waste known as Fed Batch Composting (FBC) with 85 kg of organic waste per bioreactor. The bioreactors were consisted of 5 ratios according to the volume of air, equal to 0%, 2.3%, 3%, 4.3% and 5.7%, and ventilation ducts were installed as 0, 1, 2, 4 and 6 pipes, respectively. The experiment was divided into 2 groups, namely, the PD2 non-additive composting group (ie FBC1-FBC5 reactors) and the experimental group with PD2 (FBC6-FBC10), as shown in Table 1.

#### 2.2.2 Organic waste feeding into the compost Bioreactors

Organic waste was prepared by collecting food waste, sorting out non-degradable components, digesting with a granulator to ≤1.5 cm in size, and mixing 75% organic waste with sawdust and rice husk ash at 12.5% each, at a total level of 25%, giving a 6: 1: 1 ration. The mixture was then divided into 2 parts for composting.

1) The first part was used for experimenting with non-additive PD2, for 5 experiments, with 1 bioreactors each, giving a total of 5 bioreactors: FBC1, FBC2, FBC3, FBC4 and FBC5 and the bioreactors each filled once to a capacity of 85 Kg. The lids were closed and the temperature, humidity, and pH measured every day.

2) The second part was used for experimenting with PD2, for 5 experiments, 1 bioreactor each, for a total of 5 Bins, including FBC6, FBC7, FBC8, FBC9 and FBC10. The PD2 consisted of 5 microorganisms, including *Pichia membranifaciens, Lactobacillus fermentum, Bacillus megaterium, Bacillus subtilis, and Burkholderia unamae.*

The PD2 was added as follows: 2 packs of PD2, total weight 50 grams, were dissolved in clean, un-chlorinated (1L), and left for 15 minutes. Molasses (2 kg) was mixed with 1L of water and poured onto 85 kilograms of organic waste. This was then made into a homogeneous mixture. PD2 solution was added to the organic waste mixture and the whole mixed.

### 2.3 Measurement tools and sample analysis methods

2.3.1 Parameters that were controlled during composting include: temperature, humidity and pH. Measurements were performed through the holes drilled in the sides of the containers at the upper, middle and lower levels of the containers (equal to 45, 30 and 15 centimeters, respectively) at 13.00 – 15.00 hours every day.

2.3.2 Analysis of compost characteristics and Germination Index testing was performed according to the composting standards of the Department of Agriculture, Thailand, TAS 9503-2005, with compost samples collected after composting for 30 days. Compost quality according to parameters and methods of analysis as shown in Table 2

**Table 1** Air ventilation volume of non added-PD2 reactors and added-PD2 reactors

| Variables | Fed Batch Composting (FBC) | |
|---|---|---|
| | Non Added-PD2 | Added-PD2 |
| 0% (U0VP) | FBC1 (Non-U0VP) | FBC6 (Inoc-U0VP) |
| 2.3% (U1VP) | FBC2 (Non-U1VP) | FBC7 (Inoc-U1VP) |
| 3% (U2VP) | FBC3 (Non-U2VP) | FBC8 (Inoc-U2VP) |
| 4.3 % (U4VP) | FBC4 (Non-U4VP) | FBC9 (Inoc-U4VP) |
| 5.7% (U6VP) | FBC5 (Non-U6VP) | FBC10 (Inoc-U6VP) |

Note: U = Under drain, VP = Ventilation pipe, non = Non Added-PD2, Inoc = Added-PD2, PD2 = Super Active Microorganisms; PD2

**Table 2 F**eatures of compost and analysis methods of TAS 9503-2005

| Features of Compost | Analysis Methods |
|---|---|
| Size of Fertilizer | CATM 01 or equivalent |
| Moisture Content and Volatile matter | AOAC 950.01 or equivalent |
| The amount of stone and gravel | CATM 01 or equivalent |
| Plastic, glass, sharp materials and other metals | CATM 01 or equivalent |
| Quantity of Organic matter | AOAC 967.05 or equivalent |
| pH | AOAC 973.04 or equivalent |
| Carbon to Nitrogen Ratio | BS 7755-3.8 or equivalent |
| Electrical Conductivity | BS EN 13038 or equivalent |
| Main Nutrients | |
| Nitrogen (Total N) | AOAC 955.04 or equivalent |
| Phosphorous (Total $P_2O_2$) | AOAC 958.01 or equivalent |
| Potassium (Total $K_2O$) | AOAC 983.02 or equivalent |
| Complete Degradation | Seed Germination Index |

*2.4 Statistical analysis*

The statistical parameters used were mean, percentage, statistical analysis with one-way analysis of variance (ANOVA) and other relevant statistics. These were determined at a 95% statistical confidence level, Comparison of the average temperature and air volume between non added-PD2 experiments and added-PD2 in each level, was done using t-test statistics and an overview obtained using ANOVA Repeated Measure with Generalized Estimating Equations (GEE).

## 3. Results and discussion

*3.1 Temperature*

FBC1 Fig. 3 (a) and FBC6 Fig. 3(b) show the reactor temperatures of the control reactors. The initial composting temperature was close to the ambient temperature. On a long period of organic waste composting, the temperature was found to be lower than the ambient temperature, up until the level $40^{th}$ day of composting. The temperature was still equal the environment at the psychrophilic phase. The FBC2 Fig.3(c) and FBC7 Fig.3 (d) compost bioreactors were found to be high at 50 °C during the first 6 and 8 days for the upper level. The temperatures of all three levels of the bioreactors (upper, middle and lower) decreased to a constant level on the $60^{th}$ day of composting.

The FBC3 Fig.4 (e) and FBC7 Fig.4 (f) compost bioreactors were found to be high at 50 °C during the first 3and 8 days for the upper level. The temperatures of all three levels of the bioreactors (upper, middle and lower) decreased to a constant level on the $44^{th}$ day of composting.

The FBC4, Fig.4 (g) and FBC9, Fig.4 (h) and Table 4, bioreactors were found to reach the maximum temperatures at 58 ºC and 59 ºC and temperature stayed within the thermophilic phase 12 and 9 days respectively, and both bioreactors maintained the constant temperature lasted 17 and 18 days of Composting

Barrington *et al*. (2003) studied the composting of grass, rice straw and sawdust by adding passive aeration through the sieve in the bottom of the bin and opening a 50 mm vent in the middle of the top cover of the degradation bin. It was found that the maximum temperature of 65°C in the period of 4-5 days. Jiewnok (2007) studied composting using rain tree leaves and water hyacinths as the main carbon source, with different ingredients in 4 groups, namely, urea, fresh tilapia fish, pig manure and sewage sludge from disused factories. It was found that the maximum temperature of each group occurred during the first 8-12 days. These temperatures were 53-58ºC, 56-58ºC, 45-52ºC and 46.5-61ºC, respectively. Sarichewin *et al*. (2016) composted food waste mixed with leaves and cow dung, at a rate 2: 1: 1, filled with air for 24 hours. The composting bin in their study had a temperature of between 45 and 66ºC. Comparing with these research, FBC4 and FBC9 (Table 4) were similar.

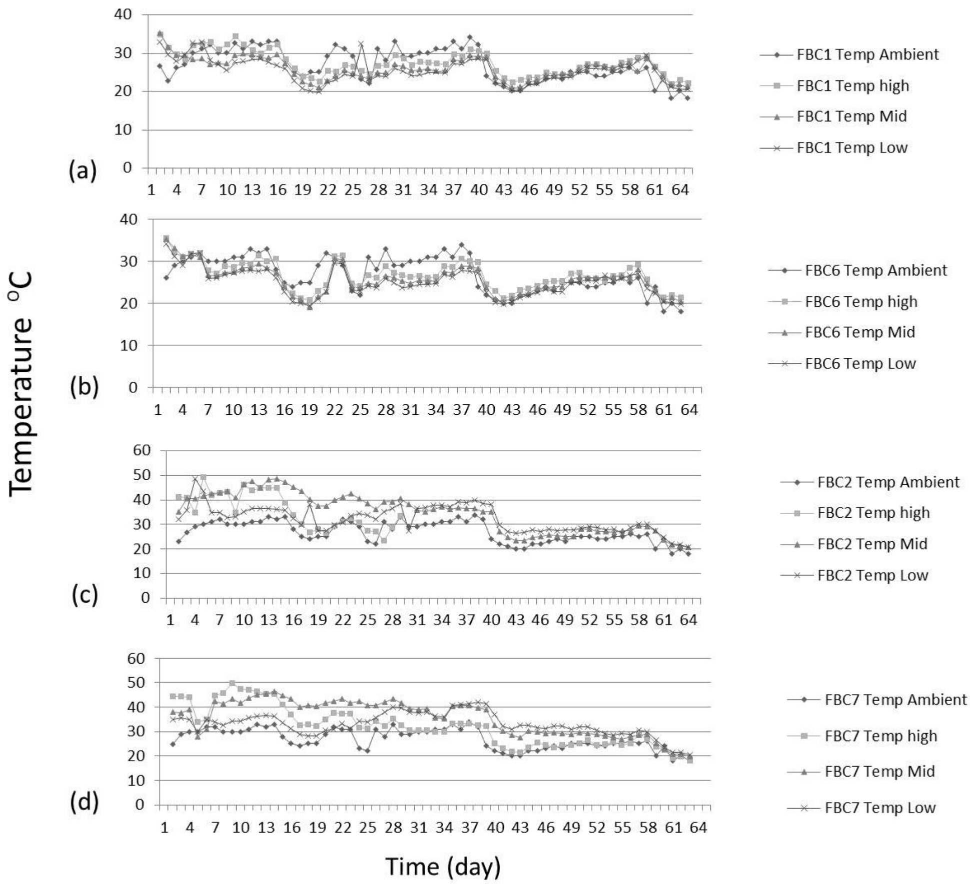


**Figure 3.** Temperature at the upper, middle and lower levels of the Fed Batch Composting bioreactors (a) = FBC1, (b) = FBC6, (c) = FBC2 and (d) = FBC7

**Table 3** Parameters and tools used for field measurements

| Parameters | Methods/Analysis | References |
|---|---|---|
| Temperature | Pocketl Thermometer | EXTECH, U.S.A. |
| pH | Soil pH Meter | TesTWest, China |
| MC | Moisture Meter | DM 300L, China |
| $O_2$ | Biogas 5000 | Geotech, UK. |

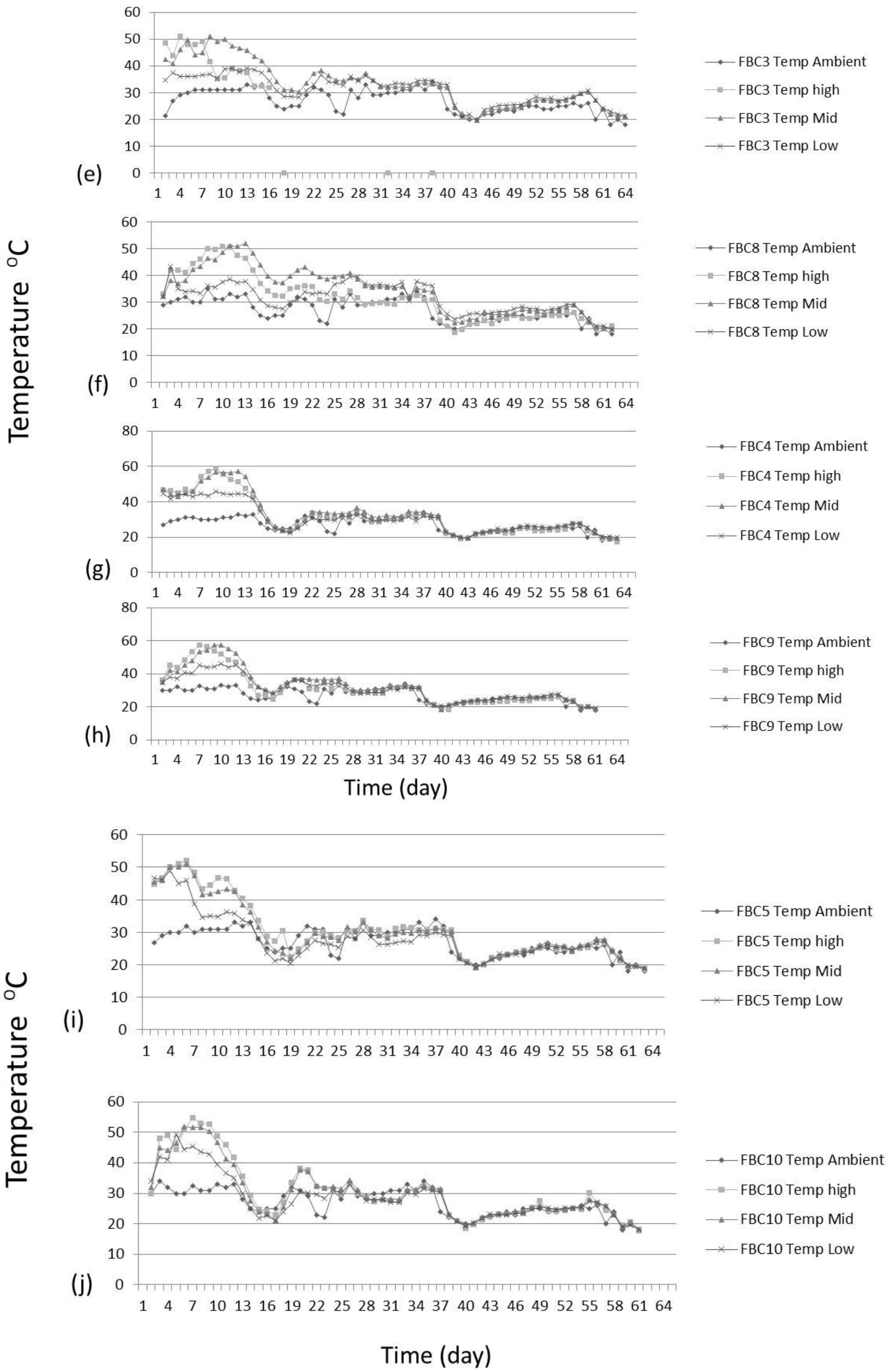


**Figure 4.** Temperature at the upper, middle and lower levels of the Fed Batch Composting bioreactors (e) =FBC3, (f) = FBC8, (g) = FBC4, (h) = FBC9, (i) = FBC5 and (j) = FBC10

**Table 4** Temperature of 10 bioreactors: FBC1-FBC10

| Parameters | Non Added-PD2 | | | | | Added-PD2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Temperature (°C) | FBC1 | FBC2 | FBC3 | FBC4 | FBC5 | FBC6 | FBC7 | FBC8 | FBC9 | FBC10 |
| Duration up to Thermophilic Phase (days) | - | 3 | 2 | 2 | 5 | - | 6 | 5 | 2 | 3 |
| Stay within Thermophilic Phase (days) | - | 6 | 10 | 12 | 9 | - | 9 | 10 | 9 | 8 |
| Maximum Temperature(°C) | 35 | 50 | 50 | 58 | 52 | 35 | 50 | 51 | 59 | 55 |
| Duration to Constant Temperature (days) | - | 44 | 37 | 17 | 17 | - | 35 | 37 | 18 | 15 |
| Duration at Temperature up over 55 °C (days) | - | - | - | 6 | - | - | - | - | 3-4 | - |

### *3.2 Constant temperature periods*

Analysis of the time at constant temperature of the No- added-PD2, FBC1-FBC5 and Added-PD2, FBC6-FBC10 indicated a period at constant temperature of 17 and 18 days, starting from the 4.3% vent volume. (Fig.5)

### *3.3 Features of compost*

Compost obtained from No-PD2, FBC4-FBC5 and Added-PD2, FBC9-FBC10 of this study met compost standards for almost all parameters, except moisture. The moisture content must be corrected by applying compost to the sun, to let the moisture decrease, before being used (Table 5).

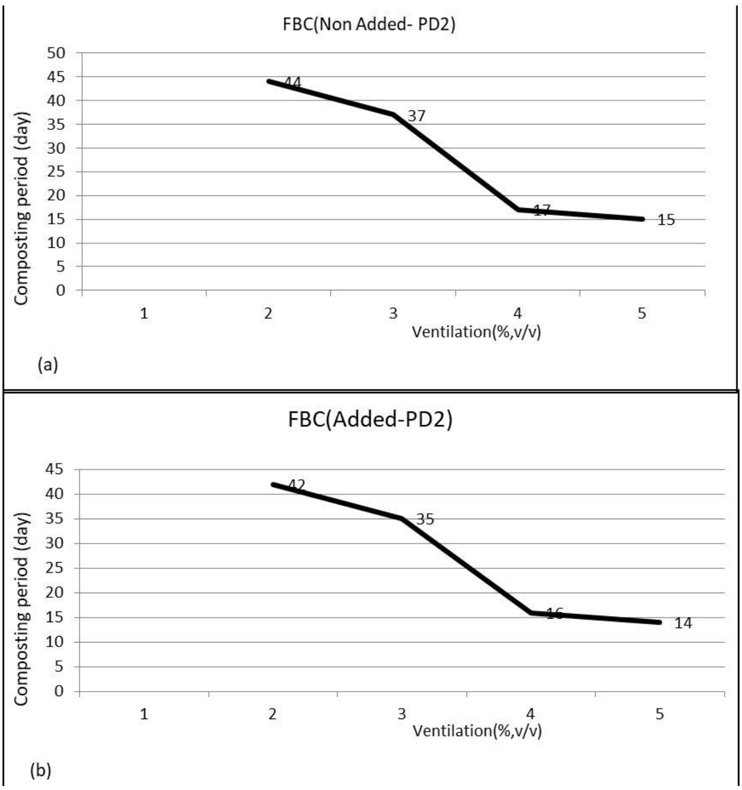


**Figure 5.** (a) and (b) time (days) at constant temperature per vent volume of Non added-PD2, FBC1-FBC5 and Added-PD2, FBC6-FBC10

**Table 5** Characteristics of compost compared to compost standards of Thailand

| Parameters (Standards) | | Non Added-PD2 | | | | | Added-PD2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FBC1 | FBC2 | FBC3 | FBC4 | FBC5 | FBC6 | FBC7 | FBC8 | FBC9 | FBC10 |
| OM (% w/w) | (≥30) | 53.54 | 56.69 | 71.31 | 60.52 | 58.08 | 62.25 | 54.08 | 62.46 | 61.17 | 65.02 |
| C/N ratio | (≤20:1) | 24 | 22 | 24 | 20 | 20 | 26 | 22 | 21 | 20 | 20 |
| GI (%) | (>80) | 15.15 | 70.85 | 75.11 | 87.20 | 86.14 | 10.24 | 72.45 | 78.85 | 85.15 | 86.10 |
| N (%) | (≥1) | 1.28 | 1.50 | 1.71 | 1.57 | 1.44 | 1.51 | 1.50 | 1.67 | 1.72 | 1.52 |
| $P_2O_2$ (%) | (≥0.5) | 0.79 | 0.88 | 0.84 | 0.93 | 0.43 | 0.70 | 0.62 | 0.70 | 0.87 | 0.64 |
| $K_2O$ (%) | (≥0.5) | 0.73 | 0.84 | 0.85 | 0.75 | 0.74 | 0.68 | 0.91 | 0.97 | 0.87 | 0.87 |
| pH | (5.5-8.5) | 6.26 | 8.72 | 8.75 | 7.82 | 8.19 | 6.12 | 8.17 | 7.75 | 7.72 | 7.94 |
| EC (dS/m) | (≤6) | 5.13 | 4.73 | 4.42 | 5.43 | 4.64 | 5.87 | 5.24 | 6.78 | 4.99 | 4.67 |
| Na (%w/w) | (≤1) | 0.79 | 1.03 | 1.03 | 1.06 | 1.11 | 0.85 | 0.97 | 0.67 | 1.00 | 0.81 |
| MC (%) | (≤35) | 66.12 | 58.42 | 52.66 | 43.25 | 41.50 | 67.92 | 55.67 | 48.65 | 41.56 | 40.50 |

*3.4 Statistical analysis*

Comparison of the germination index (GI) between non added PD2 and added PD2 by used statistical analysis: t-test (Normality distribution) revealed that GI of two group were no significantly different *(p-value >0.05).*

Comparison of average temperatures of Non added-PD2 and added-PD2, using t-test statistics and the overall using ANOVA Repeated Measure with Generalized Estimating Equations (GEE) (n = 189) revealed that the average temperatures of the two groups were no significantly different *(p-value >0.05)*, indicating that added-PD2 had no effect on the degradation of organic waste

## 4. Conclusions

Fed Batch Composting found that the proportion of organic waste that was filled once time was appropriate if the amount of passive aeration volume was at least 4.3 percent of the bioreactor volume. Temperature measurement indicated the activity of microorganisms in the bioreactors(FBC4 and FBC9), showing a rise to the thermophilic phase within 2 day, stayed constant for 9-12 days, and peaked at a maximum temperature of 58-59 OC, staying at above 55 °C for at least 6 day.

The time series of this experiment was as follows: 85 kg of organic waste was added once time(Fed Batch), with constant temperature reached at 18 days from the start date, and curing continued for another 2 weeks, total composting period of 30 days. There was complete degradation, with the index between 85-87 percent. The resultant composts complied with Thai compost standards. The temperature comparison between Non-PD2 and Added-PD2 had no statistically significant differences.

Suggestions for improving the results when composting from both FBC4 and FBC9 with 4.3% vents include: installing 4 pipes for ventilation; the addition of organic waste, mixed with rice husk ash and sawdust at a ratio of 6: 1: 1; crushing food scraps to a small, 1.5 cm, diameter; and adding 85 kilograms of composting materials once per a bioreactor, as well as using non added-PD2.

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