Effect of external heat source on temperature and moisture variation for composting of food waste

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Abstract. This paper investigates the outcome of having an external heat source on temperature and moisture variations in the food waste composting process. Food waste accumulation is a growing concern in many countries. Converting food waste into usable compost is a more desirable tactic than dumping to crowded landfill sites. Closed composting was applied in this work, which relies on a controlled but uninterrupted airflow during the organic material degradation process. However, undesirable odour released at low aeration rate due to low temperature and high moisture content found in the compost. Finding the ideal aeration rate with the least possible loss of moisture is needed, which was discussed in this paper. The vegetable-fruit waste used in the experiment was given an aeration rate of 0.3 L/min at a moisture setting of 60% and 70%. For 15 mins/day, the forced aeration was carried out at 3-day intervals. Results showed that 0.3 L/min with 60% and 70% moisture content attained best temperature peaks of 32.4°C and 31.6°C, respectively at day 13 for 28 days composting. A strong odour continued to exist with the compost and was mitigated by using an external additional heat source (light bulb). The light bulb also helped to provide a higher temperature for the compost of 41.5°C by day 1 for 10 days composting.

1. Introduction

A very large amount of total solid waste in Malaysia (around 50% to 60%) will comprise municipal solid waste, which is mostly food waste. This creates numerous concerns in the local context and internationally as the problem is the same in most countries. The food waste originates from daily markets (24.5%), restaurants (23.4%) and from domestic household (38.2%) environments [23]. These can then be categorized into three types, food losses, unavoidable food waste and avoidable waste. It should also be noted that this waste will continuously increase with the population, with Malaysia’s 32.45 million people producing food waste parallel to the population growth [1].

The bulk of this waste makes its way into landfills, as approximately 95% of the total municipal solid waste, which amounts to around 10.5 million tons of waste, will be disposed of in operating landfills [2]. This is expected to increase by around 31,000 tons of waste by 2020 [3]. Despite the relative ease with which this waste can be disposed of, it emits greenhouse gases. High odor emission is also a problem, along with the space constraints. With a population increase of 2.4%, the landfills are piling up very fast and there will be a shortage of landfills, with large costs incurred in finding new landfill.
sites [4]. The treatment of municipal waste has not been investigated extensively, and therefore landfill operation continues as one of the accepted methods [5].

Composting is seen as one acceptable method of getting rid of degradable waste, however, it is not seen as a successful method. The low value of compost products is one reason, along with the pollution that occurs from gas emissions, despite changes made to reduce such emissions [6]. The factors taken into consideration include the moisture content, temperature, aeration rate, porosity, and the Carbon-to-Nitrogen (C:N) ratio. The composting material can vary significantly and therefore there will be differences in the quality of the compost, with poor quality compost being a major concern [7].

The temperature of the food waste compost is observed to show which phase the compost is currently at. The microbial activity inside the compost can also be observed from the temperature changes that occur. It has been concluded from former research that composting temperature reflects on the degradation rate of the compost, where a higher temperature of 50°C to 70°C reflects a higher degradation rate [8]. Alternate research, however, indicated that 70°C will inhibit microbial activity [9]. Instances where quick rapid external heating was used did not benefit microorganism growth. Their optimum temperature range was observed to be 45°C to 70°C for a thermophilic phase within 3 to 4 days for the total elimination of pathogens. Ranges like this are observed for the thermophilic phase (figure 1). The mesophilic phase was also observed to help in elimination where mesophilic bacteria initiates the microbial activity [10]. Achieving the desirable temperature is a challenge, as the compost pile in most cases obtains the highest possible temperature at a maximum of 38°C, which means there is insufficient elimination of pathogens. The low temperature observed indicates that the compost did not reach the status of thermophilic phase, rather it remains composting at the mesophilic phase. This can be concluded as an effect of high moisture contents ranging from 92% to 94%. Low heating values are observed for the vegetable waste as well. Convection heat loss can be experienced when performed in the laboratory reactor [11].

![Figure 1. Range of composting temperature at different phases.](image)

Another experiment used carton and vegetable waste composting, which was able to conclude that the compost will achieve peak temperatures of 45°C to 50°C. This can be observed due to low isolation of the composting vessel and the smaller volume [12]. It resulted in a period of composting of 308.33 days, which was longer. Self-regulating heat in a sample will allow the temperature to slowly increase and drop under anaerobic conditions. A suitable growing temperature is acquired by the microbes and the remaining organic matter will mature in the short thermophilic phase [9]. It can therefore be concluded that the compost temperature and thermophilic phase are highly correlated in order to obtain a high-quality compost amount, while remaining at the thermophilic phase for a longer period.

Much like the thermophilic phase, moisture plays a crucial role in the composting process. Moisture, created by the addition of water, will carry the necessary nutrients for the physiological and metabolic
activity of the microorganism. Previous research has indicated that the moisture content is a dominant factor in an experiment with compost which takes a toll on the microbial activity [13]. The experimental work was justified with the need for 50% moisture content, which indicated that an increment in the temperature can be realized with increased moisture content alone. This does, however, require further research. Food waste will, in most instances, have very high moisture contents, which will cause a longer composting period for most experiments. It is also a clear indication of the low degradation efficiency when it comes to composting [9]. Previous research suggests that the ideal moisture content for the bulk of composting materials will be in the range of 50% to 70% [14]. Another experiment showed impressive results by finding green vegetables with the combination food waste co-composting will provide a standalone moisture content of 60% [10].

The moisture content and the ratio of the bulking agent used will be related. This was evident from a previous experiment when large ratios of bulking agent were used on leftover food waste at a ratio of 70:30 of bulking agent to food waste which showed no leachate formation for home composting [15]. When the food waste was higher than the bulking agent, for example, with a ratio of 30:70 of bulking agent to food waste, there was gas exchange, unpleasant odour and an inclination toward the anaerobic process. Reasoning behind this may be due to the high moisture exceeding the absorption capacity of the bulking agent used. Therefore, the moisture content will need to be controlled effectively along with the bulking agent to food waste ratio in order to get the ideal temperatures required and the best composting process.

Improper selection of aeration rate and mode could slow down the breakdown process of organic waste, resulting in a thermophilic phase that could not be achieved in a laboratory scale of composting reactor. In past research, composting mixture aerated in continuous mode at high rate could achieve C:N ratio below than 20 to show a good usability of the final product [17]. Higher aeration is typically chosen to achieve good composting performance as well as to obtain a good quality of final product. However, usage of high aeration and continuous aeration mode could induce high operating cost. Besides, high aeration rate could result in extensive moisture and heat loss, which would cause a longer time to reach maturity of stage in the composting process. In contrast to high aeration rate, the anaerobic condition would be developed at different pile regions if low or not enough air is pumped into the compost pile [19]. This is unfavourable as anaerobic condition would cause odour problems and lengthen the composting process to attain maturity stage. Thus, intermittent aeration mode is proposed to pump oxygen into compost pile within the intervals with the appropriate pumping time, resting time and aeration rate. By adopting intermittent aeration mode, moisture and heat loss as well odour problem could be reduced since there would not be excessive pumping of air into the compost pile. Pumping air into the compost pile and resting within the period where the oxygen saturation falls would cause conservation of energy and enhancement of composting quality [20]. Intermittent aeration could also reduce the total greenhouse gases (GHG) emission by 17.8% compared to continuous aeration mode [20]. Though intermittent aeration sounds to be more economical and efficient than continuous aeration mode, substantial finding is required to justify the usage of intermittent aeration for composting of food waste, which is limited at present and arguable.

Households are responsible for most of the food waste in Malaysia. The main food waste from these households include rice, vegetables and meat [21]. It is generally grouped into 60% carbohydrates, 20% protein and 10% fats. Fruits and vegetables are definite sources of carbohydrates, thereby making them the predominant wastes from Malaysian households. Though meat is also a part of household food waste, it will not be applied in the composting process due to risk of pest infestation if not handled adequately [22]. This process is likely not favoured by the general public. Therefore, this study will utilize fruits and vegetables as the main substrate in the mixture. Besides, most research findings found that the thermophilic phase could not be achieved in a small scale of composting system. With the aim to improvise home composting on food waste, a light bulb is proposed to attach inside the composting vessel as an affordable source to assist temperature rise during the composting process. Self-regulating heat is typically slow and not able to be maintained in a small-scale composting system, thus an external heat source is required to compensate for the heat loss in this system.
Taking all these factors into consideration, this paper will investigate numerous factors, including the effect of additional heat sources on temperature and moisture changes during composting of food waste with intermittent aeration technique. The work will investigate the potential similarities between the aeration rate and high peak temperatures which allows the compost pile to mature in a shorter time period.

2. Materials and methods

2.1. Raw materials
In order to create a mix of food waste, the following items were used: vegetable waste (raw uneaten green vegetables waste), fruit waste (left over fruit peels), and spent coffee grounds. These were collected from the local market, a coffee shop and a juice stall. The fruit along with the vegetable waste were cut into pieces ranging from 1.5 to 2.5 cm in size to promote degradation rate [18], and then mixed in with the rice husks and spent in coffee grounds. Rice husk is the bulking material in this experiment, and it was added as a source of carbon to regulate the carbon to nitrogen ratio of the food waste mixture, along with its moisture content. The ground coffee, acquired from a coffee shop as a byproduct of its brewing process, was added as a nitrogen source to balance the carbon to nitrogen ratio. The containers used were 5 L capacity water dispenser units with a dimension of 29.0 x 19.7 x 10.1 cm. These had holes cut into them to perform intermittent aeration. The vessels had a mixture of 300 g vegetable waste, 200 g fruit waste, 450 g coffee ground, and 50 g rice husk. Carbon to nitrogen (C:N) ratio was maintained at 23, which was ideal for the initial composting process. The type of green vegetable waste and fruit peels were fixed in each collection to ensure uniformity of the mixture in each experiment. Sampling was done in each preparation to make sure the initial C:N ratio of the mixture had fulfilled the requirement.

2.2. Experimental setup and composting procedure
The container that was described in Section 2.1 was used with the necessary additions carried out to it. Initially, the system was designed to investigate the optimum aeration rate which will assist in providing a temperature that is high for the longest possible time period. In the meantime, a fixed moisture content was retained without a source of heat. The experiment then proceeded to introduce a heat source and identify the peak temperatures as well. The external heat source used was a light bulb, which generated substantial amounts of heat. This is so that the compost will be able to climb to a higher temperature profile, to eliminate the odor, and to cut down the composting period due to rapid degradation rate. The differences in results between the experimental part with an external heat source and without an external heat source will be useful in understanding the usefulness of an external heat source.

The experiment required five important components for each vessel: the water dispenser, heat insulator, pump and tube, moisture sensors, and temperature sensors. These were connected to a microcontroller which will display the data at the location itself and upload the data online to ThingSpeak, an open source IoT platform, which will help remotely log the data. The water dispenser used was a high-density polyethylene 5 L capacity water dispenser (figure 2 (a)), made from a high quality PP5 material. Containing polypropylene, which has a melting point of 167°C, this vessel displays good heat resistivity and is therefore suitable for the job. The heat shield used was a Xinfrax Aluminium Heat Shield (figure 2 (b)). This was to help establish the thermophilic phase, which was a technique used for a closed composting system which can allow the self-regulating heat of the microbial to take place. Minimum heat loss subsequently occurs due to this insulation. The air pump used was the variety normally utilized in aquariums (figure 2 (c)). It has a maximum capacity of 3.0 L/min and is utilized in order to supply air flow during the composting period. It provided aeration rate supply ranging from 0.1 to 1.0 L/min for the various vessels. A silicon tube was used to penetrate the compost in the vessel, and there were holes cut into it to evenly distribute the distilled water or air. The tube size was approximately 2.5 to 3.0 cm.
The sensors were attached toward the center of the vessel using drilled holes, with the hole for the air pump being the vessel’s premade openings (figure 3). Each vessel used had its own respective temperature sensors and moisture sensors, along with a temperature sensor placed outside the system to measure ambient temperature. The temperature sensor used was the DS18B20 waterproof system, and the moisture sensor was a low-cost YL-69 hydrometer sensor, which has previously been calibrated and tested for use with various soil samples [16].

For the initial experiment, where no external heat source was used, the vessels were placed on tables with closed pipes placed for air pump fixing when needed (figure 4 (a) and (b)). The microcontroller setup was kept at the center of the set of vessels, where the YL-69 moisture sensors were connected to a microcontroller with internet connecting capabilities, the Node-MCU unit (figure 5). Since there were multiple sets of moisture sensors and the microcontrollers have limited analog inputs, multiplexer modules were used to measure numerous sensors at the same time. This was not needed for the temperature sensors as each sensor had a unique ID and multiple sensors could be read through one digital GPIO pin. Since continuous current flow through the moisture sensors would cause them to rust, relay modules were placed which were controlled by the microcontrollers, which would switch on the moisture sensors for the time duration when they were measured.
Figure 4. Illustration of the closed composting system used for the project.

The moisture sensors were calibrated by inserting them into samples with known moisture content levels and then using the model with the compost system. The equation obtained in Section 2.3 was used to adjust the moisture content of compost to the set point of 50, 60 and 70%. The moisture sensors and temperature sensors were first installed using hot glue and then the compost was carefully inserted into the vessel. Nine vessels were prepared and given the aeration rate and moisture content in table 1. This aeration was supplied using the aquarium pump and was supplied every Monday and Thursday at the same time for 15 minutes. The system was then gently shaken to evenly distribute the compost and air. Distilled water would be added into the vessel when moisture content is reduced. The composting was carried out for 28 days without any additional heat source.

Table 1. Aeration rate with the moisture content for the nine composting vessels.

| Vessel | Aeration Rate, AR (L/min) | Moisture Content, MC (%) |
|--------|---------------------------|-------------------------|
| A1     | 0.3                       | 50                      |
| A2     | 0.6                       | 50                      |
| A3     | 0.9                       | 50                      |
| A4     | 0.3                       | 60                      |
| A5     | 0.6                       | 60                      |
| A6     | 0.9                       | 60                      |
| A7     | 0.3                       | 70                      |
| A8     | 0.6                       | 70                      |
| A9     | 0.9                       | 70                      |
Figure 5. Microcontroller setup.

The second portion of the experiment used the external heat source in order to achieve a higher temperature profile. A 58-Watt tungsten incandescent candle bulb with screw base was chosen because this light bulb could emit more heat than a fluorescent lamp. The light bulb used as a heat source performed the additional task of odor elimination. A faster degradation rate was also achieved with the heat source. The three highest peak temperatures found using the first portion of the experiment were the ones repeated for the second section using the additional heat source. Figure 6 shows the composting vessels with the desired aeration rate and moisture content based on the results from the first section. Yellow was the least desired, red was moderately desired, and green was highly desired.
Figure 6. Composting vessel with light bulb installation. (Yellow — least desired aeration rate, red — medium desired aeration rate, green — most desired aeration rate).

Vessel openings were sealed using hot glue in this instance as well. Similar to the first portion of the experiment, the aeration and moisture content were kept controlled. The food waste used was then allowed to decompose for 10 days provided the compost had reached a state of maturity. Samples were tested with the same parameters after the experiment was carried out.

2.3. Monitoring and analysis
The YL-69 moisture sensor was calibrated using two methods. The two methods are compared to ensure a certain degree of accuracy when using the system. Firstly, the drying oven method was used where oven dried samples with known moisture contents can be measured using the YL-69 sensors (figure 7 (a)). The other method was the standard soil gravimetric method where a food waste sample had water mixed into it to calculate the moisture value (figure 7 (b)).

Both methods had obtained a 4th degree polynomial equation and linear regression analysis was used to determine the accuracy of the moisture sensors. The equations were then used to measure the moisture of the compost samples. The initial values were collected in bits, as the analog signal received from the moisture sensor gave a value between 0 and 1024. These bit values, along with the calibrated moisture percentages were uploaded online to the ThingSpeak server, where they can be downloaded when required.

Sampling was done to determine properties of final compost. For pH measurement, the sample was used to prepare aqueous extract at a 1:10 compost: water ratio (w/v) and mechanically shaken for 1 hour. The pH was then measured with a pH meter [17]. Same sample was used for electrical conductivity (EC) measurement, where the EC was measured with an EC meter. For C/N ratio analysis, 100 g of sample was sent to the Nabbir Laboratory Sdn Bhd (Kuching) for Total Organic Carbon (TOC) and Total Kjeldahl Nitrogen (TKN) analysis. The C/N ratio was then calculated by dividing TOC with TKN.
3. Results and Discussion

Table 2 displays the maximum temperatures observed during the experiment without the use of light bulbs. Forced aeration was carried out as mentioned previously. The tabulated moisture values were given by moisture sensors, which were calibrated by standard soil gravimetric method with 5.02% error. It shows a more promising accuracy in predicting moisture content of food waste compost as compared to the drying oven method with 10.06% error.

Vessel A4 is the vessel with the highest peak temperature of 32.38 °C in a 28-day composting period. This is the highest value which came about a low aeration rate of 0.3 L/min. Vessel A7, which also contained a 0.3 L/min aeration rate, has a significantly high temperature. Vessel A9 is the notable exception, with a 0.9 L/min aeration rate and a high temperature. It is therefore possible to conclude that if a medium and low aeration rate can achieve higher peak temperatures, it is unnecessary to use higher aeration rate for the composting procedure to reach a higher peak temperature. It can also be observed that the aeration rate impacts the temperature profile, as the aeration rate has a relationship with the oxygen supply for microbial activity. It should be noted however that the temperatures do not exceed 32.38 °C for the experiment, and there it is not considered as a good food waste composting stage as the mesophilic phase has not been reached. This phase would be where the mesophilic bacteria start killing pathogens at temperatures of 35 °C and above.

![Model of drying oven method](image1)

![Model of standard soil gravimetric method](image2)

**Figure 7.** Bit Value recorded for YL-69 Sensor vs Moisture Content (%) for (a) drying oven method and (b) gravimetric method.
Table 2. Maximum temperature achieved during 28 days of composting.

| Vessels | AR (L/min) | Peak T (°C) |
|---------|------------|-------------|
| A1      | 0.3        | 31.13       |
| A2      | 0.6        | 31.81       |
| A3      | 0.9        | 31.75       |
| A4      | 0.3        | 32.38       |
| A5      | 0.6        | 31.25       |
| A6      | 0.9        | 31.57       |
| A7      | 0.3        | 31.63       |
| A8      | 0.6        | 31.38       |
| A9      | 0.9        | 31.81       |

Figure 8, 9 and 10 indicate the points at which the moisture content for the best vessels was observed at varying aeration rates. Vessel A4 had a moisture content of 50.05% to reach the peak temperature in 13 days. Within 16 days, for the medium aeration rate, the most attractive aeration rate was achieved by vessel A2 at 31.81 °C with a moisture content of 60.05%. The use of a high aeration rate 0.9 L/min achieved temperature of 31.81 °C happened to show a moisture content at 80% by day 3. This shows that a high aeration rate will provide a high moisture content inside the compost. The 0.6 L/min aeration rate and the 0.9 L/min one, showed similar temperature peaks. This did differ greatly in its moisture content. High aeration rates can be rejected as a choice which justifies this better. A large enough moisture content can reduce the degradation rate, resulting in a longer period of composting. Considerably low aeration rates can provide a high temperature profile at 50.05% moisture content. This shows that the moisture content was enough to transport the dissolved nutrients, necessary for microbial activity. Vessel A9 most likely experienced an excessive amount of cooling with high levels of moisture content. This certainly created a difficulty in obtaining higher peak temperatures even with the use of high aeration rates. Water vapour was observed on the walls of the composting vessel as the experiment was being carried out, which shows that evaporation has occurred inside the vessel. Water vapour could be observed dropping back into the compost which certainly led to increased moisture content levels. It is likely that this phenomenon occurred in vessel A2 and A4, even though it had achieved a higher temperature peak. It should be noted that it did not achieve a mesophilic phase. Moisture content can be seen to heavily influence the low temperature profiles.

Figure 8. Peak temperature achieved at a low aeration rate of 0.3 L/min in a 28-day composting period.
Figure 9. Peak temperature achieved at medium aeration rate of 0.6 L/min in a 28-day composting period.

Figure 10. Peak temperature achieved at a high aeration rate of 0.9 L/min in a 28-day composting period.

Figure 11 shows the ranking of the top 5 vessels with the highest peak temperatures. This helped to pick the best three vessels for use with the heat source in the next part of the experiment. The first vessel selected was vessel A4. It used a low aeration rate and moisture content set point of 60% to achieve 32.38°C. A2 and A9 were the next vessels chosen. Vessel A2’s reason for being selected is due to the temperature of 31.81°C being achieved with medium aeration rate without the need for a high aeration rate. Vessel A9 is then not selected due to its use of high aeration rate and a high moisture content in relation (%). One of the vessels from A3 and A7 needed to be picked as well and they recorded peak temperatures of 31.75°C and 31.63°C respectively. In this case, a higher peak temperature is reached by aeration rate of 0.9 L/min compared to lower aeration rate. However, A7 is selected as the dominant first vessel, as it displayed the highest peak achieved from the vessels with a low aeration rate. A7 is chosen instead of A3 due to its aeration rate and optimum moisture content.

The three selected vessels, A2, A4, and A7 were then experimented with for a 10-day period. A 58-Watt light bulb is used for providing an additional heat source in each of the vessels. The resulting peak temperatures are displayed in table 3.
Figure 11. Peak temperature achieved by the top 5 vessels.

Table 3. Temperature measurements for selected 3 vessels during 10 days of composting.

| Vessels | AR (L/min) | T (°C) | Period to peak T |
|---------|------------|--------|-----------------|
| A2      | 0.6        | 39.69  | Day 1           |
| A4      | 0.3        | 41.50  | Day 1           |
| A7      | 0.3        | 39.94  | Day 3           |

The 58-Watt light bulb is introduced as the extra heat source. With this new heat source, vessel A4 can be seen to show a high peak temperature recorded at 41.5 °C for a 10-day period of composting. The aeration rate used is low, which is at 0.3 L/min. The moisture content set point thus varies the three vessels composting condition as shown in figure 12 below.

Figure 12. Maximum peak temperature against days to reach peak temperature.
It may be seen that with the extra heat source the composting process has accelerated the degradation rate of the microbial movement. From figure 12, the peak temperature was reached within 24 hours for all 3 vessels in a 10-day period. This is roughly 12 days earlier than without the use of the external heat source. Degradation rate is precisely indicated as the increase of temperature from its ambient of approximately 27.89 °C is observed. A difference of 13.7 °C was noted for vessel A4 with a low aeration rate of 0.3 L/min and 50% moisture content. Medium aeration’s temperature peak for 0.6 L/min with 50% moisture content was 39.69 °C. Apart from a noticeable rise in temperature, the rise occurred significantly fast in this case as well.

Figure 13 shows that the aeration rate of 0.6 L/min which was able to reach 39.7 °C within 24 hours contains a moisture content of 53%. This can be considered relatively optimum as the set point for moisture content of the compost is 50%. Meanwhile, figure 14 indicates that the aeration rate of 0.3 L/min can obtain the highest peak temperature of 41.5 °C. This was also achieved within 24 hours and had a moisture content of 58%. The moisture content set point is at 60%. Figure 15 shows 0.3 L/min with a moisture content of 70% as its set point. This last vessel has a notable difference, where, at the period of peak of 48 °C, it had a certain degree of moisture. A substantial reduction in moisture was observed at this point where a temperature of 39.94 °C is recorded, thus explaining that the vessel cannot climb to a higher peak temperature. It can be explained as being due to the exhaustion of nutrient supply for the microbial activity. When comparing vessels A2 and A4, the moisture content was maintained. This shows that enough nutrient and oxygen is available for medium and low aeration rate vessels to obtain a high peak temperature.

Figure 13. Moisture Content (%) and high peak temperature of A2 with medium aeration rate of 0.6 L/min.
Figure 14. Moisture Content (%) and high peak temperature of A4 with medium aeration rate of 0.6 L/min.

Figure 15. Moisture Content (%) and high peak temperature of A7 with medium aeration rate of 0.6 L/min.

Table 4. Final physicochemical parameters for the 3 selected vessels after 28 days composting.

| Vessel | AR (L/min) | C:N  | pH   | EC (μS/cm) | Peak T (°C) |
|--------|------------|------|------|------------|-------------|
| A2     | 0.6        | 19.11| 7.31 | 578        | 31.81       |
| A4     | 0.3        | 18.59| 5.21 | 702        | 32.38       |
| A7     | 0.3        | 20.07| 5.58 | 819        | 31.63       |

The final physicochemical properties of the 3 best vessels without the heat source is shown in table 4. A pH of 4.17 was recorded from all the vessels used. This can be understandable and is likely from the ingredients of the food waste mixture. The mixture consisted of banana peels, green vegetables, orange skin and coffee grounds. The acidity can be notably due to the orange skin, as oranges are known for their acidic properties. The pH value, in the beginning, most likely has been impacted by external sources. This could most likely be the acidity of the food waste type. All 3 of the vessels that were selected, A2, A4 and A7 gave a notable increment in the pH value during the 28 days of composting. The degradation phase’s occurrence is apparent due to these observed readings. Vessel A2 is the only one that fell within the acceptable range of 7 to 8, for the final pH value. Vessels A4 and A7 recorded slightly lower pH values. In terms of a final product indicator, this is considered quite poor, possibly...
due to the degree of aeration being insufficient or an insufficient supply of oxygen. The pH values can most certainly naturally vary. This could be resulting from the waste type used.

A carbon to nitrogen ratio of 22.46 was recorded for the total set of vessels in the beginning. The final C:N ratio for the 3 vessels in table 4 above showed ratios below 21. In detail, vessel A2 had a C:N of 19.11 and A4 had a C:N of 18.59. A7, on the other hand, had a value that is somewhat higher, at 20.07. The initial composting was planned for 40 days, but it was achieved in 28 days, as seen by the results above. This can be justified by referring to figure 8, 9 and 10, where, after a time duration of 22 days, the graph trends indicated that the stability of the compost is at a temperature range that is similar. The maturity of the compost is confirmed by this. It is therefore unnecessary to extend the composting period which was done within a short time period of 28 days. The result shown here also means that the experiment started off with a good C:N ratio. The somewhat high C:N ratio in Vessel A7 can be explained as being due to a moisture content that is elevated. This most likely made the composting period longer. It can also be concluded that A7 will perhaps need a composting duration that is more than 28 days in order to achieve a C:N ratio of 20.

The electrical conductivity results that were given above give information on the salt content. This content is mainly in the form of magnesium and calcium which is found inside the compost. A substantial difference is not observed among the vessels as compared to the initial EC value of 739 μS/cm. It is evident from the research that the vessels will all be under the acceptable range for the EC (< 30,000 μS/cm).

There was a strong odour emission produced throughout the experimental procedure which is not surprising as the temperature profiles are all noted to be less than 35 °C. This creates the notion that there is no active phase of bacteria killing.

A rough coarse kind of texture was observed with the food waste mix. Initially it was roughly 2.0 cm to 2.5 cm. After 28 days of the composting procedure, a clear conversion of the food waste into compost was observed, which met the requirement of usability. A darker shade was observed for the product and it could now be termed as a sort of fertilizer. Smaller particle sizes were observed, and it resembles a rough kind soil texture (figure 16 (a) and (b)).

![28 days composting](image)

**Figure 16.** Initial (a) and final (b) stage of compost.

| Vessel | AR (L/min) | C:N  | pH   | EC (μS/cm) | Peak T (°C) |
|--------|------------|------|------|------------|-------------|
| A2     | 0.6        | N/A  | 7.96 | 987        | 39.69       |
| A4     | 0.3        | 18.59| 7.79 | 1075       | 41.50       |
| A7     | 0.3        | N/A  | 7.54 | 693        | 39.94       |

In the event of the vessels with the heat source attached, the readings are as indicated in table 5. An acidic pH property of 4.17 was recorded for all the vessels. This was like the food waste mixture which
consisted of banana peels, orange skin, coffee ground, and green vegetables. Vessel A2, A4 and A7 have shown an increment in the pH value for a duration of 10 days. This increased pH value shows that there is degradation taking place, which makes the product very appealing for use as a source of compost.

An initial C:N ratio of 22.46 was recorded for all the vessels and vessel A4 had attained the requirement of C:N ratio below than 20 to indicate good usability of the final product. Vessel A2 and A7 were not selected for C:N ratio measurement due to their peak temperature being below 40, which did not fulfil the purpose of adding heat source to the composting vessel. This study aimed to raise the temperature of the compost pile by using affordable sources such as attaching light bulbs in the second experiment. The electrical conductivity of all the vessels was under an acceptable EC of 30,000 μS/cm and below. No emission of odour was reported for this second experiment, which is not surprising as the temperature profile was recorded to be higher than 40 °C which would show that bacteria killing has begun. The physical changes appear to be like the first part of the experiment (figure 17 (a) and (b). A very dark shade was observed for the final product. It can be said to resemble the look of a common fertilizer. The usability of this product was justified clearly in relation with its C:N, pH and EC.

![Figure 17. Initial (a) and final (b) stage of compost.](image-url)

**4. Conclusions**

Acknowledging the importance of composting food waste, the effects of external heat sources on the temperature and moisture variations in food waste composting has been provided in this paper. The effect of these additional heat sources has been investigated in order to observe the temperature and moisture changes during composting of food waste with the intermittent aeration technique. The experiments explained the possibility of shortening the composting period from 28 to 10 days with the addition of a heat source. Minimal loss of moisture has occurred with the use of an intermittent aeration rate instead of a continuous aeration rate. In the 28 days of composting, intermittent aeration at rate of 0.6 L/min with 50% moisture content and 0.3 L/min with 60% and 70% moisture content had showed the highest temperature peak of 31.8°C, 32.4°C and 31.6°C respectively by day 16 compared to other vessels. However, all vessels had strong odour emission. Hence, an additional heat source (light bulb) was utilized to minimize the release of unpleasant odour. A higher temperature profile between 39.7°C and 41.5°C was attained within 1 day in the second part of the study with 10 days composting. The forced aeration with intermittent mode and low aeration rate has shown a good composting process. Further optimization results showed that intermittent aeration with aeration rate between 0.2 to 0.3 L/min can achieve a high temperature profile with peak temperature of approximate 42°C achieved within 24 hours. In addition, these low aeration rates will also create less odour and reduce the loss of moisture content. The final product has properties of C:N ratio below 20, pH in range of 7–8.5, EC below 30,000 μS/cm and moisture content between 40–60% that make it a great fertilizer. These research findings act as a groundwork for future experimentations on utilizing intermittent aeration at low rate to compost the food waste. The high temperature is achievable with use of low aeration rate and composting process...
can be sped up to days or hours to avoid long accumulation of waste. With this, a simple automated home composting system can be built with an improvising to this groundwork.

References

[1] Worldometers 2017 World population prospects Worldometers
[2] Muhd Yunus M N and Abd Kadir K Z 2006 The development of municipal solid waste treatment technology based on refuse derived fuel and bio-gasification integration Proc. of the International Symposium on Renewable Energy: Environ. Protection and Energy Solution 762
[3] Sreenivasan J, Govindan M, Chinnasami M and Kadiresu I 2012 Solid waste management in Malaysia — A move towards sustainability Waste Manag. An Integr. Visions 55–70
[4] Kathirvale S, Muhd Yunus M N, Sopian K and Samsuddin A H 2004 Energy potential from municipal solid waste in Malaysia Renewable Energy 29 559–67
[5] Wan A and Kadir W R 2001 A comparative analysis of Malaysian and the UK London England Addison-Wesley Publishing Company Inc.
[6] Sakawi Z 2010 Municipal solid waste management in Malaysia: Solution for sustainable waste management J. Appl. Sci. Environ. Sanit. 6 29–38
[7] Cerda A, Artola A, Font X, Barrena R, Gea T and Sanchez A 2018 Composting of food wastes: Status and challenges Bioresour. Technol. 248 57–67
[8] Guo W Y, Zhou Y, Zhu N W, Hu H G, Shen W H, Huang X X, Zhang T P, Wu P X and Li Z B 2018 On site composting of food waste: A pilot scale case study in China Resour. Conserv. Recycl. 132 130–8
[9] Li Z T, Lu H W, Ren L X and He L 2013 Experimental and modeling approaches for food waste composting: A review Chemosphere 93 1247–57
[10] Kumar M, Ou Y L, and Lin J G 2010 Co-composting of green waste and food waste at low C/N ratio Waste Manag. 30 602–9
[11] Chang J I, Tsai J J and Wu K H 2006 Composting of vegetable waste Waste Manag. Res. 24 354–62
[12] Rawoteea S A, Mudhoo A and Kumar S 2017 Co-composting of vegetable wastes and carton: Effect of carton composition and parameter variations Bioresour. Technol. 227 171–8
[13] Liang C, Das K C and McClendon R W 2003 The influence of temperature and moisture contents regimes on the aerobic microbial activity of a biosolids composting blend Bioresour. Technol. 86 131–7
[14] Iqbal M K, Shafiq T and Ahmed K 2010 Characterization of bulking agents and its effects on physical properties of compost Bioresour. Technol. 101 913–9
[15] Guidoni L L C, Marques R V, Moncks R B, Botelho F T, da Paz M F, Correa L B and Correa E K 2018 Home composting using different ratios of bulking agent to food waste J. Environ. Manag. 207 141–50
[16] Tan W Y, Then Y L, Lew Y L and Tay F S 2019 Newly calibrated analytical models for soil moisture content and pH value by low-cost YL-69 hygrometer sensor Measurement 134 166–78
[17] Gao M, Li B, Yu A, Liang F, Yang L and Sun Y 2010 The effect of aeration rate on forced-aeration composting of chicken manure and sawdust Bioresour. Technol. 101 1899–903
[18] Jolanun B, Towprayoon S and Chiemchaisri C 2008 Aeration improvement in fed batch composting of vegetable and fruit wastes Environ. Progress 27 250–6
[19] Trautmann N 1996 Compost physics Cornell Waste Management Institute
[20] Tao J, Li G X, Tang Q, Ma X G, Wang G and Schuchardt F 2015 Effects of aeration method and aeration rate on greenhouse gas emissions during composting of pig feces in pilot scale J. Environ. Sci. 31 124–32
[21] Hafid H S, Rahman N A A, Shah U K M, Baharuddin A S and Ariff A B 2017 Feasibility of using kitchen waste as future substrate for bioethanol production: A review Renew. Sustain. Energy Rev. 74 671–86
[22] Storino F, Arizmendiarrrieta J S, Irigoyen I, Muro J and Aparicio-Tejo P M 2016 Meat waste as feedstock for home composting: Effects on the process and quality of compost *Waste Manag.* 56 53–62

[23] Abd Razak S, Abd Ghafar S W, Mohd Padzil N A, Kamaruddin A, Mat Zin N, Saim M and Suhaimi A H M S 2018 Household food wastage prevention in Malaysia: An issue processes model perspective *Economic Technol. Manag. Rev.* 13 51–62

**Acknowledgments**

This research project acknowledges the support from the Faculty of Engineering, Computing and Science and Chemical Engineering Research lab for continuous accommodating the needs of this project.