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Effects of Temperature, Aeration Rate and Reaction Time on Composting of Empty Fruit Bunches of Oil-Palm

V. S. Jie Wei*, C. Han Bing, A. Saptoro, J. Nandong

Faculty of Engineering and Science, Curtin University Sarawak Campus, CDT 250, 98009 Miri, Sarawak, Malaysia

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A B S T R A C T

Composting is a biochemical process in a controlled aerobic environment where thermophilic microorganisms stabilize organic waste substrates into valuable humus-like products. Three parameters which are known to affect the composting process including temperature, aeration rate and composting time. This research aims at developing a model to describe the relative influence of different temperatures, aeration rates and reaction time on the composting process and how it affects the final quality of EFB compost produced. EFB samples were mixed with urea as a source of nitrogen and fresh compost as inoculum. The composting process was carried out in a composting test bench for a total of 42 days. The moisture content was found to be significantly affected by temperature and reaction time. Carbon loss was significantly affected by all three factors. Nitrogen content was affected by aeration rate, reaction time as well as interaction between temperature and reaction time. Changes in total ions over time showed a positive correlation with the value of conductivity (Pearson correlation coefficient of 0.853) and the largest reduction in C/N ratio (from 30.2:1 to 17.6:1) was obtained at temperature of 40°C and aeration rate of 0.4 L/min kg. The results of this study could form a basis for palm oil mills to improve the quality of EFB composts produced within a short maturation period and with low C/N ratio.

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INTRODUCTION

Malaysia's palm oil industry has been rapidly growing over the decades and currently stands as one of the top producers and exporters in the world [1]. However, palm oil mills have been categorized as major contributors towards serious environmental issues due to the accumulation of solid and liquid biomass [2], emission of greenhouse gases [3] as well as being associated with deforestation and loss of biodiversity [4]. Major waste products from the mills include oil palm empty fruit bunch (EFB) and palm oil mill effluent (POME), which accounts for high annualdisposal costs [5]. The total generation of solid oil palm residues is annuallyaround 44 million tons, with EFB comprising of 23.8 million tons (54%) [1]. Conventional methods of dumping EFB into landfills not only requires large space, but causes pollution hazards and discomfort due to bad odor from the degradation of residual oil [6]. Burning or incineration of EFB generates airborne pollutants and emits acidic gases such as sulfur dioxide and nitrogen oxides which causes acid rain [7]. This method, however, is no longer a common practice due to stringent environmental regulations on air pollution. Unlike other by-products from the palm oil mill, EFB can be reused directly without any pre-treatment [2]. The current practice of disposing EFB back into the plantation for mulching purposes and nutrients recycling helps in restraining the growth of weeds, avoiding erosion and maintaining the soil moisture [8]. This method, however, is also not feasible, as it results in eutrophication and an increase in the toxicity level of soil [9]. Other problems arising from this include long degradation time, attracting pests, high transportation costs and distribution costs [10, 11].

To overcome all the shortcomings of conventional EFB handling methods, composting, a biological-based process has been introduced as a viable alternative to stabilize the organic matter into valuable end-products [12, 13]. In composting, higher plant materials are broken

*Corresponding author: Vivienne Sim Jie Wei
E-mail: vivienne.sim@gmail.com; Tel:+60149443850

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down by aerobic thermophilic microorganisms present in the waste to produce nutrient-rich humus-like materials [14-16]. The composting process comprises of three stages which are high rate composting, stabilization and maturation in order to fully degrade the organic wastes, destruct pathogenic micro-organisms and form stabilized materials [16, 17]. Advantages of composting include being economically feasible [18], reduces emission of greenhouse gases [11] as well as aids in recovery of materials by returning treated organic wastes through a natural cycle [19]. The maturity of composts is usually determined from characteristics such as its color, odor, temperature, pH, cation exchange capacity and C/N ratio [20, 21]. The compost is said to have reached maturity when a C/N ratio of less than 20 is obtained [11, 22]. This ratio is favorable to growth of plants as plant roots are only able to absorb the N if the ratio of C:N is 20 or lower [23]. Common issues faced in composting of EFB include long formation time and low nitrogen content [11].

The composting process can be affected by a number of environmental parameters such as temperature, pH, conductivity, moisture content, agitation and aeration rates as well as substrate characteristics such as size of feedstock, initial C:N ratio and nutrient contents. In this study, two parameters; temperature and aeration rate have been manipulated to find out their relative influence on the composting process. Composting temperatures vary throughout the whole process as a response towards the microbial activities and can be divided into four distinct stages which are the mesophilic phase, thermophilic phase, cooling phase and maturation phase [24]. A high initial temperature of 55-65ºC is needed in order to destroy pathogens, but in the mesophilic phase, high temperatures will cause most of the microorganisms to die [25]. High temperature also increases the rate of emission of ammonia [18, 26, 27]. In order to overcome these problems, a temperature of 40-55ºC is most desirable to be maintained throughout the composting process to enhance microbial activity and reduce the loss of nitrogen [24, 27].

Aeration provides oxygen in a composting system through various means such as physical turning, natural convection or forced aeration [28]. A minimum oxygen concentration of 5% is essential for aerobic decomposition [29]. Aeration aids in destroying the anaerobic regions that exist within the pile [18], speed up the composting process and ensure high nitrogen values in mature compost [14]. However, if the aeration rate is too high, energy transfer increases, leading to a decrease in temperature [28]. Studies have shown that the most favorable rates of aeration differ depending on the composting materials. Some of the optimal values obtained are 0.4 L min^{-1} kg^{-1}for mixture of agriculture wastes [28]; 0.48 L min-1 kg^{-1}for mixture of pig feces and corn stalks and 0.4 L min^{-1} kg^{-1}in an active municipal solid waste [30].

Various studies have been carried out on EFB to determine the effects of environmental parameters on the final quality of EFB compost using different mixtures for co-composting. However, limited data is available on the changes of substrate characteristics with respect to time as well as their correlation with environmental parameters in order to gain a better understanding of the composting process. Therefore, this study aims at developing a model to describe the relative influence of different temperatures and aeration rates on the composting process and how it affects the final quality of EFB compost produced. The changes in the trend of conductivity and total ions found in the EFB compost are also observed to determine the correlation between these two parameters.

MATERIALS AND METHODS

Preparation of materials

This study was carried out in a tailored-made lab-scale composting test bench with optimized conditions. Pressed and shredded EFB and fresh compost (after 15 days of composting to ensure presence of consortium of bacteria) were obtained from Bintulu Lumber Development (BLD) Sdn Bhd, Sarawak, Malaysia as materials for study. The fresh compost served as a source of inoculum to initiate the composting process and urea (CH_4N_2O) as supplementary nutrient. EFB were air-dried and shredded into lengths of two millimetres (mm); mixed with 10% of fresh compost and urea, by weight 0.5%.

Experimental procedures

The composting process was carried out in a tailored-made 25L lab-scale bioreactor connected to a computer for control of variables. A total of 3kg substrates was placed in the bioreactor for each run. A total of 5 runs were carried out based on the 2^k factorial design with the optimal conditions obtained from literature review as control set. A hot water jacket was used to manipulate the temperature (32, 40 and 48°C) and an air flow meter to change the aeration rate (0.32, 0.4 and 0.48 L min^{-1} kg^{-1}) for a total of 42 days in each run. Aeration was provided through compressed air supply where the air was humidified by passing through a washing bottle containing distilled water. Sample A was conducted at the mesophilic condition at 40°C with an aeration rate of 0.4 L min^{-1} kg^{-1}. The respective composting conditions for the remaining samples were as follows: Sample B (32°C and 0.32 l min^{-1} kg^{-1}), Sample C (32°C and 0.48L min^{-1} kg^{-1}), Sample D (48°C and 0.4L min^{-1} kg^{-1}) and

Sample E (48°C and 0.48L min^{-1} kg^{-1}). The moisture content of the samples were monitored to maintain a value of 40-60%.

Sampling and analysis

Sampling was done weekly to find out the trend in the changes of compost characteristics over time. At each sampling occasion, sub-samples were taken from the top, bottom and middle of the pile to ensure a homogeneous mixture of sample. Samples were dried in the oven at 105°C for 24 hours to determine the moisture content. Water extracts from the EFB samples were prepared in a ratio 1:10 (w/v) in order to analyze the pH and conductivities. The suspensions were shaken at 300 rpm for 1 hour using a mechanical shaker, filtered through 0.45 µm membrane filters, and tested for pH and conductivities using SevenMulti Mettler Toledo. All tests were repeated three times and results presented in this paper are the mean values obtained. Weekly samples were also sent to Nabbir Laboratory in Kuching, Sarawak, Malaysia to test for elements such as Carbon (gravimetric method), Nitrogen, Phosphorus, Potassium, Calcium, Iron, Magnesium, Manganese and Zinc (USEPA 6010 B). Experimental data were analyzed using Design Expert to determine the effects of temperature and aeration rate on the changes in physical and substrate characteristics.

RESULTS AND DISCUSSION

The proximate analyses results for the initial and final physicochemical properties of EFB compost are shown in Tables 1 and 2.

TABLE 1. Initial physicochemical properties of EFB compost

Sample	A	B	C	D	E
MC%	61.39	64.85	61.86	60.43	62.07
pH	7.60	7.64	7.49	7.74	7.44
C (mS/cm)	2.67	2.40	2.49	2.55	2.45
TI%	4.39	3.88	4.10	4.10	4.13
C/N ratio	30.20	30.53	31.01	31.63	32.50
C%	41.37	42.13	40.00	41.12	40.63
N%	1.37	1.38	1.29	1.30	1.25

Note: MC = moisture content, C = conductivity, TI = total ions, C = carbon and N = nitrogen

TABLE 2. Final physicochemical properties of EFB compost

Sample	A	B	C	D	E
MC%	48.35	51.85	49.48	42.11	40.89
pH	7.72	7.82	7.66	7.82	7.64
C (mS/cm)	2.91	2.70	2.83	2.88	2.76
TI%	5.04	4.33	4.49	4.76	4.75
C/N ratio	17.60	20.05	20.51	19.06	20.40
C%	32.39	32.68	32.40	33.55	33.45
N%	1.84	1.63	1.58	1.76	1.64

Note: MC = moisture content, C = conductivity, TI = total ions, C = carbon and N = nitrogen

Moisture content

Figure 1 shows the changes in moisture content for all samples over a composting period of 42 days. The moisture content of all the samples were found to fluctuate in the beginning but gradually stabilizing and decreasing towards the end of the composting period. Overall, samples D and E (48°C) shows higher reduction in moisture content compared to the others, with a final value of 42.11 and 40.89% (Table 2) respectively. The decrease in moisture content could be due to high temperature which leads to higher evaporation rates and cause microorganisms to die, including those involved in the composting process [25]. Sample E showed the lowest moisture content throughout the process due to higher aeration rate (0.48 L/min.kg), which resulted in higher loss of water. The fluctuation in the moisture content of the samples throughout the composting period may be due to different metabolism of a diverse species of bacteria and fungi present at the different stages in the composting process [31]. Fluctuation and uneven distribution of moisture within a composting system has been associated with a reduction in microbial activities [8].

Statistical analysis on Design Expert shows that loss in moisture content is greatly affected by temperature (p-value = 0.001) and composting time (p-value = 0.0067). Changes in moisture content can be described by the empirical model moisture loss = +14.05 +3.36T +2.19t. A F-value of 33.39 and R-squared value of 0.9303 shows that the model is significant.

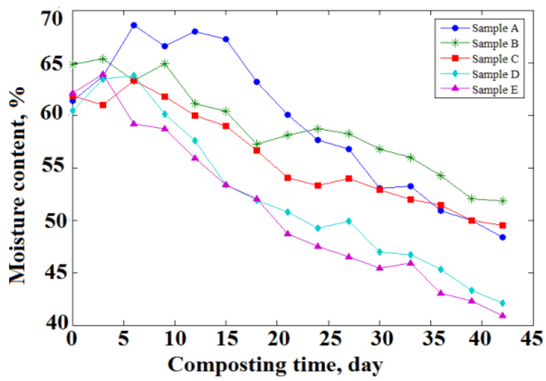

Figure 1. Changes of moisture content against time

pH

Figure 2 shows the changes in pH of all compost piles over time. The pH values do not vary significantly over the composting period despite the changes in temperature and aeration rate, and ranges from a value of 7.44 to 8.42. All compost piles show a similar trend, where a sharp increase in the pH value was noted at the beginning, then gradually decreasing and stabilizing at a slightly alkaline value at the end of the composting period. The pH of sample A, B, C, D and E with an initial value of 7.60, 7.64, 7.49, 7.74 and 7.44 (Table 1) increased to 8.42, 8.37, 8.31, 8.38 and 8.31 over the first nine days. The initial increase in the pH value may be due to the ammonification process, where bacteria involved in the initial stage break down and release ammonia from the compost. Microbial activity involving mineralization of organic acids and nitrogen during the initial phase of composting also causes an increase in the pH of the compost pile [32, 33]. In the second phase, the pH value gradually decreased and stabilized at slightly alkali values of 7.72, 7.82, 7.66, 7.82 and 7.64 (Table 2) respectively for the five different samples, possibly due to the volatilization of ammonia and release of H+-ions from the nitrification process [33, 34]. The decomposition of organic matter as well as production of organic and inorganic acids during the later phase also results in a drop in the pH value [32].

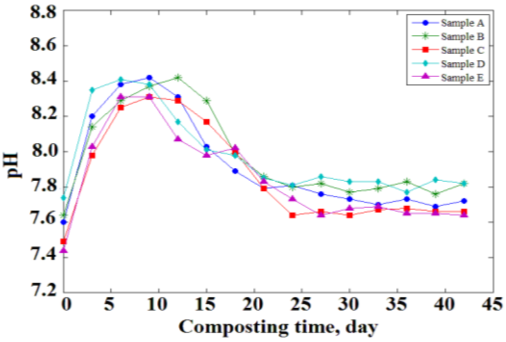

Figure 2. Changes of pH against time

Electrical Conductivity and Total Ions

Electrical conductivity (EC) represents the salinity (total salt content) and also reflects the quality of compost as a fertilizer [35, 36]. High EC may indicate more available nutrients but a value exceeding 4 mS/cm has an adverse effect on plant growth resulting in low germination rate and withering of plants [35]. Figure 3 shows the conductivity trend of the composts over time. The EC of the samples do not vary significantly throughout the composting period. The trend indicates a fluctuation over time but shows an increase in the overall value from the initial to the final, indicating an increase in the total available nutrients. The total ions (phosphorus, potassium, calcium, iron, magnesium, manganese and zinc) also show an increase from the initial to final value as shown in Figure 4. Statistical analysis on the data shows a Pearson correlation coefficient of 0.853 between EC and total ions. The fluctuation in EC and total ions over time could be caused by the microbial activity resulting in utilization and release of different nutrients and ions during the different phases of composting [31].

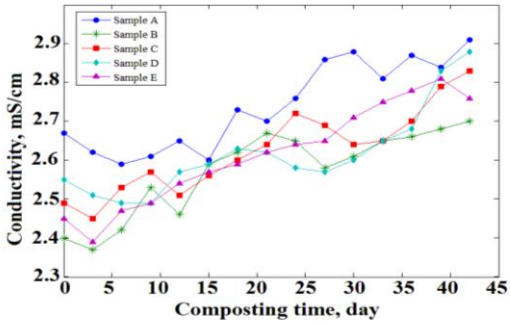

Figure 3. Changes of conductivity against time

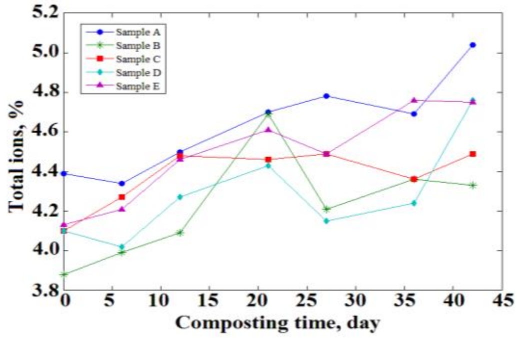

Figure 4. Changes of total ions against time

C/N Ratio

Figure 5 shows the changes of C/N ratio during the period of composting. The C/N ratio was found to decrease with time at the beginning but showed fluctuations towards the mid-phase and the end of the composting period. This may be due to the different rates of carbon utilization and nitrogen fixation at different phases of composting. The lowest C/N ratio (from 30.2:1 to 17.6:1) was obtained a temperature of 40°C and aeration rate of 0.4 L/min kg. Only two samples (A and D) obtained a C/N ratio of below 20. C/N ratio can be used as a measure to define the nutritional balance in a the compost [25]. Carbon serves as a primary energy source for the microorganisms whereas nitrogen is necessary for microorganism cell function and growth [24].

Carbon Content

In this study, it is found that the percentage of carbon, C decreases gradually over time as shown in Figure 6.

This indicates C utilization by the microorganisms as it serves as a primary energy source [24]. Sample B showed the highest C loss (9.45%) followed by sample A (8.98%). Both samples D and E showed lower C loss at 7.57% and 7.18%, respectively. Higher temperature resulted in lower C utilization possibly due to the destruction of certain species of microorganisms which

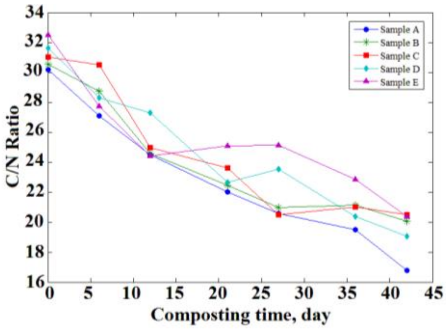

Figure 5. Changes of C/N ratio against time

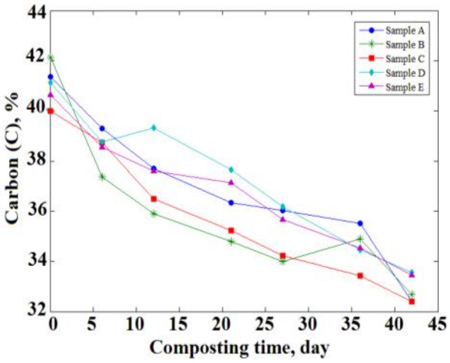

Figure 6. Changes of C content against time

are involved in composting process [25]. Statistical analysis showed that C loss is significantly affected by temperature (p-value = 0.0112), aeration (p-value = 0.0264), reaction time (p-value = 0.0057) as well as interaction between temperature and aeration rate (p-value = 0.0419). The rate of C loss can be described by C loss = +6.95 -0.79T -0.58Ae +1.00t +0.48T·Ae. The F-value of 27.60 and R-squared value of 0.9735 for the model shows that the empirical model is significant.

Nitrogen Content

The percentage of nitrogen, N content in the compost fluctuates as shown in Figure 7. Increase in N content may be due to the mineralization and active microbial cellulolytic degradation of complicated molecules in which releases N and other ions into the compost [37]. Volatilization of ammonia, on the other hand causes nitrogen loss as it is released into the air as ammonia gas [36]. High N increase was found in sample A (0.47%) and sample D (0.46%) whereas sample B and C showed low final N content (Table 2). High temperatures and aeration rates have previously been associated with an increase in the rate of emission of ammonia [18, 26, 27].

Statistical analysis showed that N content is greatly affected by reaction time (p-value = 0.0364), interaction between temperature and aeration rates (p-value = 0.0253) as well as temperature and reaction time (p-value = 0.0097). The change in N can be described as N = +0.31 +0.040t -0.045T·Ae + 0.060T·t. The predicted empirical model is significant with a F-value of 14.40 and R-squared value of 0.9153.

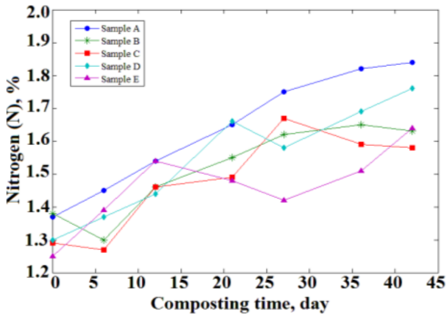

Figure 7. Changes of N content against time

CONCLUSIONS

Changes in physico-chemical characteristics of compost are affected by temperature, aeration time as well as composting period. The change in moisture content is related to temperature and composting time and can be described as Moisture loss = +14.05 +3.36T +2.19t. Carbon loss is significantly affected by temperature, aeration and reaction time. The changes in carbon content can be described as Carbon loss = +6.95 -0.79T -0.58Ae +1.00t +0.48T·Ae. Nitrogen content changes as a function of reaction time, combination of both temperatures and aeration rates as well as combination of both temperature and reaction time.

The changes in nitrogen content can be modeled by Nitrogen = +0.31 +0.040t -0.045T·Ae + 0.060T·t. Electrical conductivity and total ions show a positive relationship with a Pearson correlation coefficient of 0.853. Future studies can focus on manipulating different environmental parameters and increasing the number of levels for the variables to develop a more detailed model to describe the composting process.

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Persian Abstract

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چکیده

کمپوست یک فرایند بیوشیمیایی در یک محیط هوازی کنترل شده می باشد، که در این محیط میکروارگانیسم ترموفیل ضایعات آلی را به محصولات ارزشمند هوموس مانند تبدیل می کند. سه پارامتر اثر گذار بر این فرایند عبارتند از: دما، زمان و نرخ هوادهی. پژوهش حاضر با هدف توسعه یک مدل برای توصیف اثر نسبی دماهای مختلف، نرخ هوادهی و زمان واکنش در فرایند کمپوست و چگونگی تاثیر آن بر کیفیت نهایی کمپوست EFB تولید شده،انجام شده است. نمونه های EFB با اوره به عنوان منبع نیتروژن و کمپوست تازه به عنوان ماده تلقیحی مخلوط شدند.فرایند کمپوست در test bench کمپوست برای چهل و دو روز انجام شد. مشخص شد که محتوای رطوبت به طور قابل توجهی تحت تاثیر پارامتر های دما و زمان واکنش قرار گرفت. همچنین از دست دادن کربن به طور قابل توجهی با هر سه عامل و مقدار نیتروژن توسط میزان هوادهی، زمان واکنش و اثرات متقابل دما و زمان واکنش تحت تاثیر قرار گرفت. تغییرات در کل یون در طول زمان نشان دهنده رابطه مثبت با مقدار رسانایی (ضریب همبستگی پیرسون برابر هشتصد و پنجاه و سه هزارم) می باشد و کاهش بزرگی در نسبت کربن به نیتروژن یک به هفده و شش دهم تا یک به سی و دو دهم در دمای چهل درجه سانتی گراد و میزان هوادهی از چهار دهم لیتر بر دقیقه به ازای کیلوگرم به دست آمد. نتایج حاصل از این مطالعه می تواند پایه ای برای کارخانه های تولید روغن پالم به منظور بهبود کیفیت کمپوست EFB تولید شده در یک دوره تکامل کوتاه و با نسبت کربن به نیتروژن کم، باشد.