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APPROPRIATE TECHNOLOGY FOR WINDROW COMPOSTING OF OIL PALM EMPTY FRUIT BUNCHES

Mohamad Firdza Shukery, Hadi Suryanto and Azmi Yahya

Department of Biological and Agricultural Engineering, Faculty of Engineering, Universiti Putra Malaysia.
43400 Serdang, Selangor D.E.
Selangor Darul Ehsan, Malaysia
E-mail : firdza@eng.upm.edu.my ; azmiy@eng.upm.edu.my

ABSTRACT

Composting of oil palm empty fruit bunches (EFB) under indoor windrow composting method with a newly developed compost turning machine was studied. The self-propelled compost turning machine was developed to mix and aerate 16 tons of pre-pressed and pre-shredded EFB in four longitudinal heaps having size of 2.50 meter width, 1.50 meter height and 12.0 meter length indoor with concrete flooring. Field performances of the compost turning machine and physical characteristics of the composted EFB were monitored throughout the 12 weeks of composting period. The average mass throughput capacity of the turning machine and total mass production of composting plot were found to be 84.83 ton/hr and 47.29 ton/hr, respectively. The average C/N ratios of the composted EFB in all the heaps had reduced from 66.30 to 29.34 (55.6% reduction) and the average heap volume had been reduced to 47.7% at the week 12th of composting period. Composting of EFB with this employed windrow composting system was able to convert large volume of bio-waste into valuable bio-compost fertilizer. Consequently, the proposed system helps in utilizing waste that produced from oil palm mill and reducing fertilizer cost that is a burden to the oil palm plantation.

Keywords*: oil palm mechanisation, empty fruit bunches, turning machine, compost technology, bio-fertilizer*

INTRODUCTION

Oil palm is one of the most important crops in Malaysia in the aspect of economy, environmental and social benefits. By 2009, the total annual processing of oil palm fresh fruit bunch (FFB) could reach to 90.5 million ton when all the available 405 oil palm mills in the country are fully on operation [1]. Schuchardt et al. [2] estimated that for every ton of processed oil palm FFB would produced about 0.6 to 1.2 m³ of oil palm mill effluent (POME), 0.23 ton of oil palm empty fruit bunch (EFB), 0.13 ton of mesocarp fibres, and 0.55 ton of kernel shells. With a total annual production of 90.05 million ton, each oil palm mill in the country would be expected to produce annually about 51,135 ton of oil palm EFB, 28,914 ton of mesocarp fibers, 122,296 ton of shells, and at least 133, 407 m³ of POME. Each oil palm mill, on a daily basis, would produce about 134 ton of EFB and 351 m³ of POME which constitute as the major unutilised bio waste from the mill since the wastes of mesocarp fibers and kernel shells has direct used as boiler fuel in the mill. The POME is generally treated in an anaerobic pond before being released into the irrigation cannels in the plantation. However, this treatment emits huge amount of methane which provides global warming threat while the pond discharge contained nutrients that provides surface and ground water pollution threat [3]. However, only 15 to 60 ton small EFB are annually utilised back to the field for mulching purposes [4]. High transportation and labour costs for distributing back the produced EFB to the field plantations is one of the main reasons for low usage of EFB for mulches. Besides that, the EFB itself has a long degradation time (generally 12 to 18 months) and thus gives slow nutrients release to the crop if it is used as mulches. Thus, despite of being applied back to the crops in the field, the produced EFB are normally dumped and left to root around the oil palm mill area.

Despite of having high growth rate and high yield, oil palm is also known to be high fertilizer consumption. The plant, when compared to other industrial plants like rubber, rice, coconut, sugarcane, tobacco and cocoa, is known to consume more than 8 to 500 times of Nitrogen, 7.2 to 704 times of Phosphorus, and 11 to 369 times of Potassium. Large amount of fertilizers used means increased fertilizer cost and ultimately increased the field production cost of oil palm FFB. The cost of fertilizer is known to be the major cost since the cost normally ranged from 55% to 65% of the total field production cost of FFB [1]. In conjunction to this, almost RM 2.7 billion had to be spent by the country in 2007 to import about 3.4 million ton of fertilizers and minerals for the oil palm plantations. Within the mentioned year, about 300,000 ton of N, 252,000 ton of P and 737,400 ton of K were used by the oil palm plantations [5]. The cultivations of oil palm and other major crops in the country rely very much on imported fertilizers and the bill of import reached RM 5.8 billion in 2007 (see Figure 1). There had been an increased of about 278.7% on the values of imported fertilizer cost from the year 2004 to 2008 (see Table 1). The price of fertilizers for the past years has been skyrocketed due to the increase in the price of world's crude oil. Within the year 2004 to 2008, the reported increased in country's cultivated major crop areas was 12.2% with oil palm alone was 15.8% while the increased in the world's crude oil price was 152.0%. Thus it indicates that the increased in bill of import for fertilizers resulted from the increased of crop cultivated and crude oil price, where the later being the most prominent contribution.

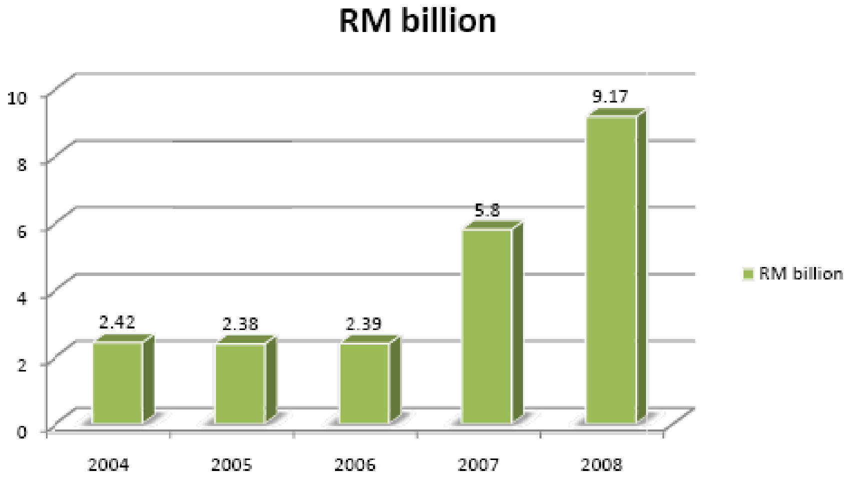

Fig. 1: Imported Fertilizer Values in Malaysian from 2004 to 2008.
Source: Sabri [5]

Table 1 :Statistics of crop cultivated area, fuel price, and imported fertilizer cost for Malaysia from 2004 to 2008.

Year	Total crop cultivated area. thousand hectares		World's crude oil price, US dollar/barrel	Total imported fertilizer cost, RM
	All crops	Oil palm		
2004	5143	3875	41.15	2,422120
2005	5310	4045	58.06	2,305758
2006	5416	4165	69.61	2,650861
2007	5534	4304	78.21	5,835952
2008	5768	4488	103.69	9,171000

Sources: Sabri [5] and Bloomberg [6]

Toward better way of utilizing agriculture waste and reducing fertilizer cost, the rich nutrients oil palm EFB could be used in the production of compost and returned back to the soil as organic fertilizer. Windrow composting is one of the practical ways to convert large volume of oil palm EFB waste into marketable end products that are easy to handle, store and use with minimal capital investment. The uses of the proper turning machine is crucial as the machine functions to introduce oxygen to compost material, accelerates physical degradation of compost material and adjust the moisture content of compost material to optimum level [7]. Most off- selves imported turning machines are unsuitable to use with oil palm EFB due to the machine huge in physical size and engine capacity and also high operation cost. Furthermore, most of the available machine systems were designed to work on animal and general agriculture wastes with have different properties than the oil palm EFB. As for these reasons, this paper would be focused on the development of an appropriate technology for composting oil palm EFB.

MATERIALS AND METHOD

Descriptions of the developed compost turning machine

The developed self-propelled compost turning machine shown in Figures 2 and 3 consists of the main chassis and engine, wheel and steering mechanism, operator console, rotor and blades assembly, and hydraulic system. The machine could be categorized as a medium size wheel type indoor windrow turner having a total weight of 3830 kg and overall total dimensions of 3.6 m in width, 1.8 m in length, and 3.1 m in height. The unique design feature about this wheel four wheel drive (4WD) and four wheel steer (4WS) machine system is that each of its pivoted traction wheels is able to make a 90˚ turn about its pivoted axis which allow for the machine to move laterally when making alignment adjustments with the compost heap position. The machine system was powered by a 60kW@2200 rpm PERKINS LOVOL 1004G water cooled, 4 cylinder diesel engine that was directly coupled to 4 in-line hydraulic pumps the consists of a 8.2 cm^3/rev@250 bar SALAMI 2PB 8.3 gear pump for running the 125.7 cm^3/rev@175 bar SAMHYDRAULIK BR130 motors for the left wheels, a 8.2 cm^3/rev@250 bar SALAMI 2PB 8.3 gear pump for running the 125.7 cm3/rev@175 bar SAMHYDRAULIK BR130 motors for the right wheels, 54.1 cm^3/rev@210 bar SALAMI 3PB 55 gear pump for running two 251.5 cm^3/rev@175 bar SAMHYDRAULIK BR250 motors for the rotor and blade assembly, and a 16 cm^3/rev@250 bar SALAMI 2.5PB 16 gear pump for running the two 63 mm bore X 300 mm stroke hydraulic cylinder for the steering left and right wheels. The rotor blade assembly has a total of 30 units of blades that make up of 5 unit of inclined tip L shaped blade located at the rotor ends and the remaining 20 units of I shaped at the rotor center. The I-shaped blades are for lifting and throwing the EFB materials rearwards and at the same time provides the possibility of cutting the EFB materials. The inclined tip L-shaped blades at the ends with blade tips projection inwards are for sweeping the EFB materials at the sides to the heap center. All the blades on the rotor are arranged in a spiral pattern arrangement that start from the rotor sides and leads towards the rotor center for the EFB materials to be thrown toward the center and allows for the rebuilding the heap. The machine system has been designed to work on a windrow heap having maximum width of 2.5 m and maximum height of 1.5 m. For the turning operation on oil palm EFB, the engine fuel throttle of the machine system has to be set running at the engine rpm of 1600 rpm while the rotor blade assembly has be set operating at 223 rpm. Such engine-rotor setting is able to provide excellent machine maneuverability and turning ability over the compost heap which ultimately after the undergoing turning operation gives a good reformed trapezoidal shape compost heap.

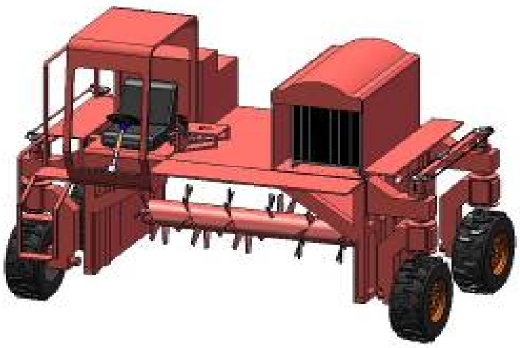

Fig. 2: 3-D CAD of the developed self-propelled turning machine.

Fig. 3: Picture of the prototype self-propelled turning machine.

Machine performance and composting process monitoring

Performance monitoring of the turning machine was conducted in an actual oil palm EFB composting production at the Biogreen Composting Plant located in Olak Lempit, Banting, Selangor. The plant is a wide

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open frame steel structure with galvanized roofing and walls and concrete flooring. The supply of oil palm EFB was directly obtained from a nearby Jenjarum Palm Oil Mill, Jenjarum, Selangor. The oil palm EFB was transported to the plant site on the same day when it was produced by the mill. The EFB had been pre-pressed to a moisture content of 50 to 60% and pre-shredded to 4 cm to 5 cm length when it came out from mill. Initially, the whole 16 tons oil palm EFB was evenly mixed together using a skid loader and then arranged using the same skid loader to form four parallel rows of equal size heap within the allocated 20 m length X 30 m flour area in the plant. Each heap has a size of 12 m length X 2.5 m width X 1.4 m height and a mass of about four ton. Aisle spacing of 1.5 m width in-between heaps, end spacing of 1.5 m in-between the side heap and wall panel, and headland spacing of 6.0 m width at row headlands were provided as the work space for the machine to travel along the heap rows and turn at headlands during turning operations. Figures 4 shows the schematic view of compost heap layout and the turning machine movements during operation. Watering operating on the compost heaps were done during the 2nd. 17th, 36 and 60th days of the composting period. The task was conducted manually by a worker using of a rubber hose that is connected to the tap water source in the plant. Turning operation on the compost heaps by the turning machine were done on every three alternate days of the composting period. Generally, turning operation for the day commences with the operator driving the turning machine toward Heap A to start off the turning operation. He steers the machine straight to complete the turning operation on the heap. Upon completing working on heap, he steers the machine for a 180° turn at the headland to enter into Heap B. He repeats the same steps of operation for Heap B, C and D. After finishing working on the Heap D, the operator drives the machine to the parking area to end the turning operation for the day. Data collections on the field performance test of the turning machine were made whenever the machine was used in the turning operation on the compost heaps throughout the 84 days composting period.

Figure 5 shows the picture of the overall experimental set-up for the compost decomposition study in the compost plant. The turning machine was measured for the average travel velocity, average wheel slippage, average turning time at headland, average engine fuel consumption, average mass throughput capacity and average compost mass production whenever it was use for the turning operation on the compost heaps. The composting heaps were daily measured for the average temperature, average moisture content and, and chemical compositions and weekly measured for the bulk density, moisture content and volumetric reduction until the complete of the composting process.

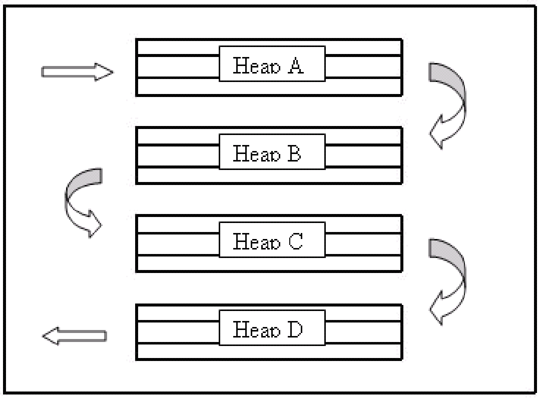

Fig. 4: Machine movements during the turning operation on the compost heaps.

Fig. 5: Overall experiment set-up for the compost decomposition study in the compost plant.

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Compost monitor OT-21 was used to measure the temperature in degree Celsius (ºC) and oxygen content in percent (%) of the composting materials in each individual heap. The temperature and oxygen content were monitored daily before start of the turning operation at five randomly selected heap cross sections within the whole length of the heap. At each selected heap cross section, both the temperature and oxygen content measurements were taken using the compost monitor at four different locations; namely the top (T), center(C), bottom1 (B1) and bottom2 (B2) as indicated in Figure 6.

Eijkelkamp B.V soil sample rings equipment with 53 mm outside diameter X 50 mm inside diameter X 51 mm height was used to measure the bulk density of the compost materials in each individual heap. The bulk density for the individual heap was monitored weekly at five randomly selected heap cross sections within the whole length of the heap. Moisture content determinations for the individual heap were monitored weekly at five randomly selected heap cross sections with the whole length of each heap. Compost samples were collected using a soil sampling core ring at the respective set depths of the selected heap cross sections. The collected was oven dry at 105°C for 24 hours and the weighing method was used to calculate the moisture content of the sample.

Solid Work 2008 Software was used to determine the heap cross sectional at five randomly selected heap cross sections of each individual heap. Figure 7 shows how height measurements were taken at weekly basis along the heap cross section to describe the heap cross sectional area. The measured heap heights at the known width locations of the heap cross section were then plotted using Solid Work 2008 Software to estimate the heap cross sectional area. The compost heap total volume was computed by multiplying the average measured cross sectional of the heap with the measured length of the heap.

Random samplings for the chemical composition analysis of the compost materials were done at five different points within the whole length of each individual heaps at weekly basis. About 100 g to 200 g of the compost material was taken inside the heap at each sampling points. These collected samples were mixed and about 300 to 400 g of the mixed material was taken places inside a sealed plastic bag. These plastic bags with the samples from the respective heaps were marked before they were sent through an express postal mail to the EPA Laboratory at Kota Tinggi, Johore for the chemical composition analysis. The conducted analysis includes C-N ratio, nitrogen content, phosphorus content, potassium content, magnesium content, calcium content, carbon content, and the organic matter content based on SIRIM MS 417 and APHA 4500H+B standards.

The machine actual travel velocity during the turning operation on the individual compost heap was calculated based on the measured total time taken to complete the turning operation on the 12 meter heap length. Knowing the total time or t_{1200} in second to complete turning the heap length, the machine actual velocity or V_a in cm/s could be calculated by the following equation:

$$V_a = \frac{1200}{t_{1200}}$$

The machine wheel slippage during the turning operation on the individual compost heap was calculated based on the earlier measured machine actual travel velocity and the corresponding machine theoretical velocity. The machine theoretical velocity was earlier determined by running the machine empty without the compost materials on a uniformly flat bituminous road for a distance of 12 meter length at the same engine throttle and

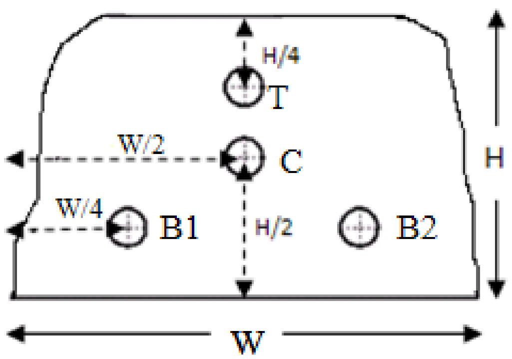

Fig. 6: Sampling points for temperature and oxygen content measurements in the compost heap.

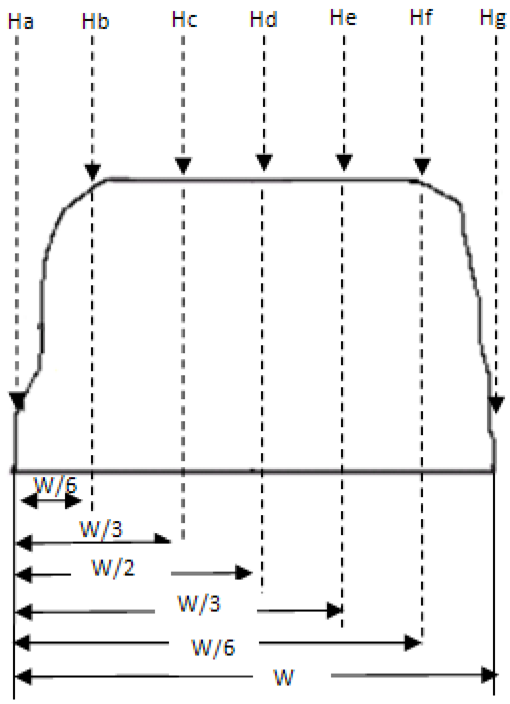

Fig. 7: Height measurements for describing the cross sectional area of the compost heap.

rotor blade settings. Knowing the machine theoretical travel velocity or V_t in cm/s and actual travel velocity or V_a in cm/s, the machine wheel slippage or S in % could be calculated by the following equation:

$$S = \left[\frac{V_t - V_a}{V_t}\right] 100\%$$

The engine fuel consumption for the turning operation was calculated based on the amount of fuel consumed by the turning machine for completing the operation on all the four compost heaps. Knowing the engine fuel consumption for the day's operation or v_t in l and the measured total time to complete the operation or t_{tot} in hr, the engine fuel consumption or F_{con} in l/hr could be calculated by the following equation:

$$F_{con} = \frac{v_l}{t_{tot}}$$

The machine mass throughput capacity on each individual compost heap was calculated based on the handled total heap mass and the total time taken to handle the heap mass. The total heap mass was estimated by multiplying the total heap volume with the measured bulk density of the compost material. Knowing the total heap mass or H_{mass} in ton and the total time taken for task or t_{mass}, the mass throughput capacity or M_c in to/hr could be calculated by the following equation:

$$M_c = \frac{H_{mass}}{t_{mass}}$$

The corresponding machine volumetric throughput capacity on each individual compost heap could be determined by dividing the obtained machine mass throughput capacity with the average bulk density of the compost material. Subsequently, the compost mass production capacity was calculated based on total heap mass the machine had to handle for the day's operation and its measured total time to complete turning operation for the day.

RESULTS AND DISCUSSION

Field performance of the machine system

The developed self-propelled turning machine was able to function effectively in conducting the in-door window turning operation on the pre-pressed and pre-shredded oil palm EFB materials. In the earlier calibration test on the machine system, maneuvering of the machine over the oil palm EFB compost heap was effective at the engine throttle setting of 1600 rpm and the lifting and throwing action of the blades was excellent at the rotor blade assembly setting 223 rpm. There was indication on some cutting action of the blades on the EFB fiber at the latter stage of the composting period when the fibers had soften from the decomposition process that occurred. The actual windrow turning with the machine system was able to be conducted successfully for a total of 34 days of operation that was distributed within the 84 days of composting period. The machine system was successfully able to monitor its field performances doing the turning operations throughout the 34 days of turning operations in the compost plant. Maneuverability of the machine system within the given minimal work space of 1.5 m aisle spacing in-between heap rows, 1.5 m end spacing between heap row and wall and 6.0 m headland spacing at row ends could be easily achieved with the available four pivoted traction wheels on the machine. Besides that, it was able to work successfully on the compost heap with 2.5 m width X 1.4 m height X 12 m length and able to reform back the heap with almost the same cross sectional shape after the machine pass.

Table 2 reveals this windrow, self-propelled oil palm EFB turning machine was able to give a mass throughput capacity of 84.83 ton/hr (or an equivalent rated compost mass production of 47.29 ton/hr) with a wheel slippage of 36.87% and engine fuel consumption of 5.05 l/hr when operating at a rated travel speed of 280.08 m/hr. The obtained field performance is very better than the 2.5 m width X 1.2 m height windrow, self-propelled oil palm EFB turning machine developed by Suryanto and Yahya [8]. The machine system was claimed to give a compost mass production of only 23.53 ton/hr with a wheel slippage of 23.2% when operating at a rated travel speed of 89.7 m/hr.

Table 2: Field performance parameters of turning machine.

Machine parameter	No. of samples	95% CI values
Theoretical travel velocity, cm/s	3	12.07 ± 0.03
Actual travel velocity, cm/s	25	7.78 ± 0.01
Wheel slippage, %	25	36.87 ± 2.03
Headland turning time, s	25	41.35 ± 4.74
Engine fuel consumption, l/hr	25	5.05 ± 0.12
Mass throughput capacity, ton/hr	25	84.83 ± 5.98
Compost mass production, ton/hr	25	47.29 ± 3.40

Physical and chemical characteristics of the compost materials

Temperature, oxygen concentration and moisture content readings of the compost materials in all the four heaps were monitored throughout the composting period for the purpose of quantifying the surrounding habitant conditions of the microbes responsible for the decomposition of the compost materials. While, bulk density, volumetric reduction, C-N ratio, nitrogen, phosphorus and potassium readings of the compost material in all the four heaps were monitored for the purpose of quantifying the extent of decomposition process that occurred on the compost materials and at the same time the present quality of the compost. The decomposition process of the compost materials by the available microbes produces heat and thus results with increase in the temperature of the compost materials within the heap. Frequent watering and turning of the compost heaps were done throughout the composting period to control and redistribute the heat within the compost heap. Besides that, the operations were necessary in order to increase the moisture content and concentration of the compost materials for the microbe decomposition activities within the compost heap.

Figure 8 shows that average temperatures of the compost materials for all the four compost heaps started to increase drastically beginning day 1st to day 3rd to the values slightly above 60°C. After day 3rd, average temperatures of the compost materials started to reduce gradually to values around 45°C on day 17th and then remained fluctuating between the 45°C to 50°c range until day 60th of the composting period. The fluctuations in the average temperature values in all the four compost heaps within this specified composting period was due to the watering and the turning activities on the compost heaps. As earlier said, these activities were conducted to maintain oxygen concentration and temperature for the available microbes within the compost heaps. After day 60th, the average temperature values of the compost materials in all the four heaps started to decrease gradually until the last day of the composting period. The decreased was much due to the decreased in the production of heat as the consequence to the reduced decomposition process by the microbes. Figure 9 shows that the average oxygen concentrations in all the four compost heaps started to decrease drastically from day 1st to day 3rd to values around 15% and the gradually increased back to values slightly above 18% on day 7th of the composting period. The average oxygen concentrations in all the compost heaps remained fluctuating between the 18% to 20% range from day 7th to day 60th. Then, from day 60th until the last day of the composting period, oxygen concentrations in all the four compost heaps almost remained to level off to values around 18%. The moisture content of the compost materials in all the four compost heaps shows gradual small increased in the moisture content from day 1st to day 14th and followed with gradual large increased in the moisture content from day 14th to day 49th and finally level of to valued around 76% until the last day of the composting period (see Figure 10). On the other hand, average bulk densities of all the four compost heap showed gradual decreased beginning from day 1st to day 14th to the values around 150 kg/m^3, continued with substantial gradual increment in the bulk densities from day 14th to day 59th, and finally maintained at values around 325 kg/m^3 from day 59th until the last day of the composting period (see Figure 11). Both the volumetric reduction and C-N ratio values of the compost materials for all the four compost heaps showed gradual decreased in their values since the beginning of day 1st to day 70th of the composting period. However from day 70th until the last day of the composting period, these values tend to level off at 50% and 0.30 values, respectively (see Figures 12 and 13). Generally, based from the obtained tends of average bulk density, average volumetric reduction, and average C-N ratio with days, it indicates that there exists minimal decomposition process by the microbes on the compost materials for all the four compost heaps from day 70th until the last day of the composting period.

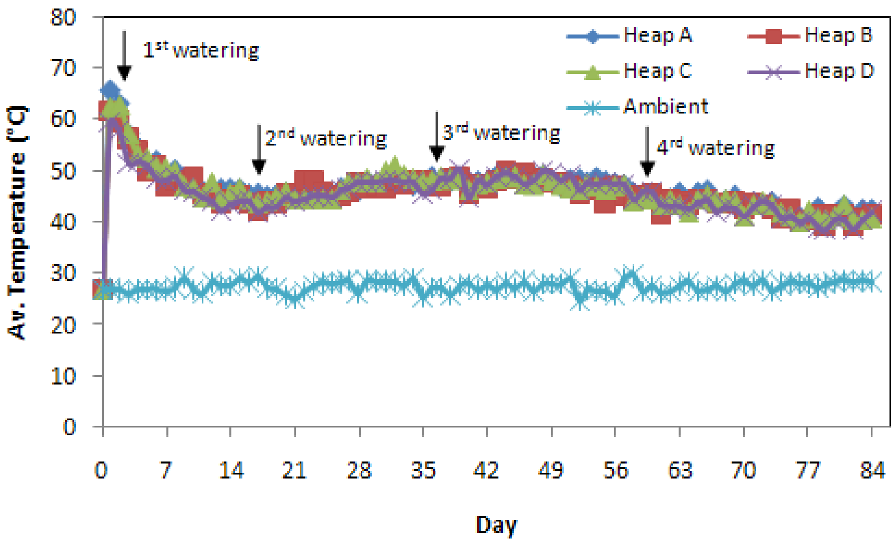

Fig. 8: Average temperature of compost materials with time.

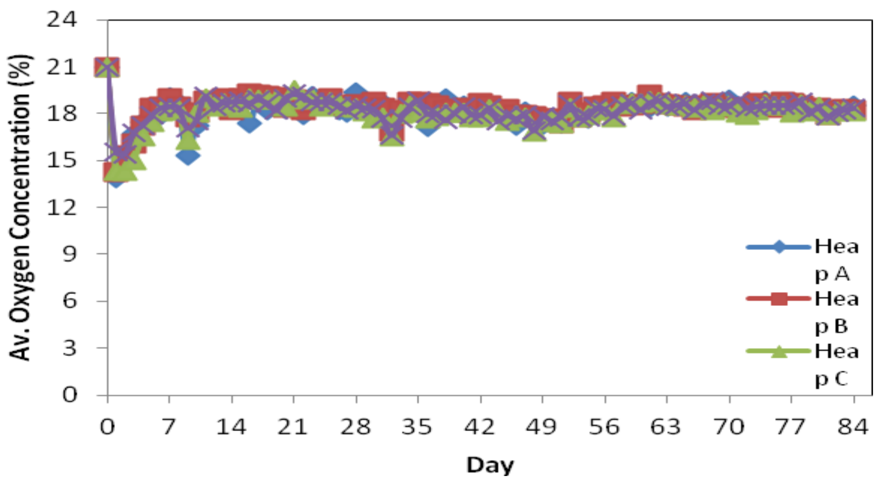

Fig. 9: Average oxygen content of compost materials with time.

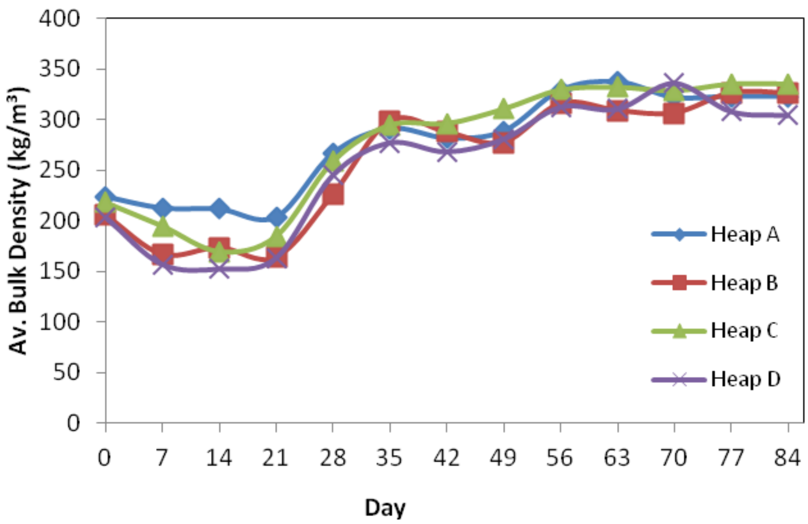

Fig. 10: Average moisture content of compost materials with time.

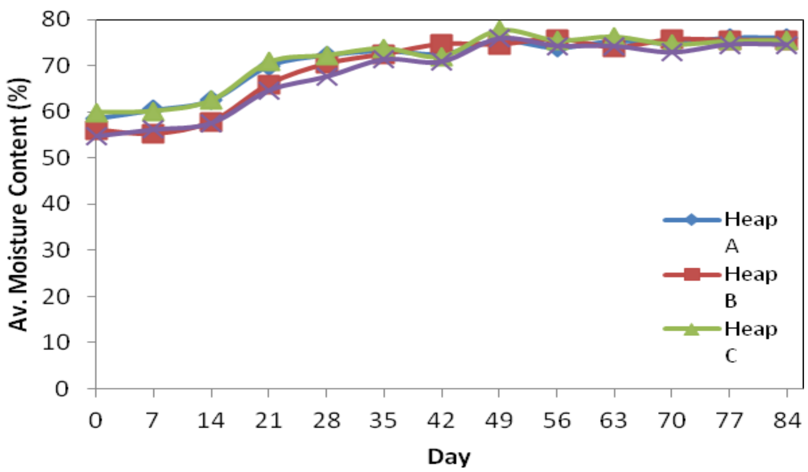

Fig. 11: Average bulk density of compost materials with time.

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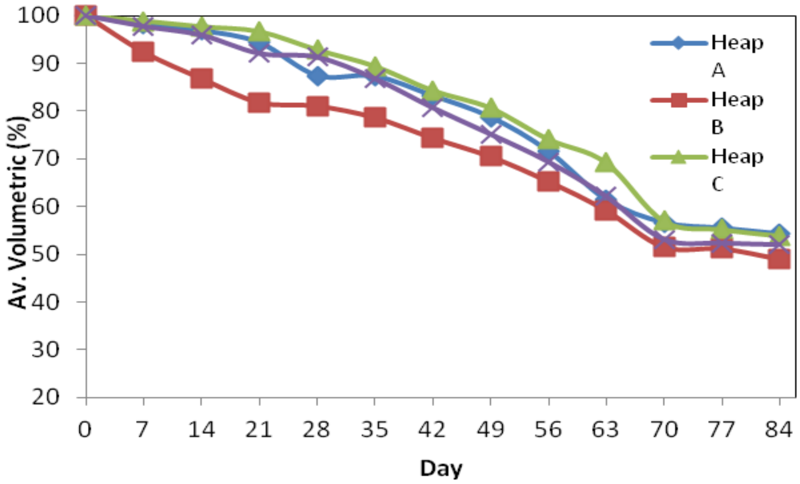

Fig. 12: Average volumetric reduction of compost materials with time.

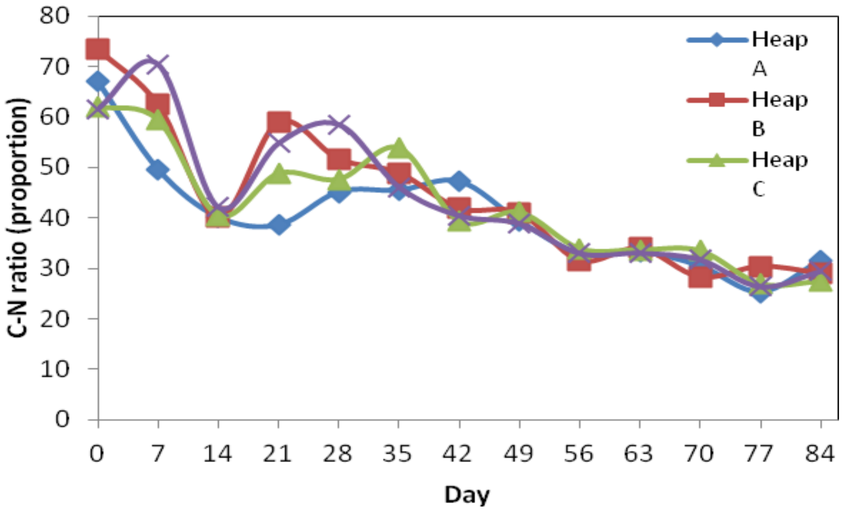

Fig. 13: Average C-N ratio of compost materials with time.

Table 3 reveals that the current adopted composting technology for oil palm EFB under the 84 days composting period was able to produce a compost with C-N ratio of 29.34, bulk density of 322.14kg/m^3, moisture content of 75%, nitrogen content of 1.70%, phosphorus content of 0.28% and potassium content of 5.64%. Increments of 24.4% in oxygen concentration, 31.6% in the mosture content, 51.4% in the bulk density, 93.2 in nitrogen content, 55.6% in phosphoris content and 161.1% in the potassium content despite decrements of 30.9% in temperature, 47.7% in volumetric reduction and 55.6% in C-N ratio were obtained on the final compost materials after 84 days of composting. Study by Thambirajah et. al [9] showed that the C-N ratios of the compost materials from shrededd oil palm EFB could significantly reduced to range of 12 to 14 within 60 days composting period with the addidition of POME, animal manure and urea in the initial prepapration of the compost materials. Similarly, Schuchardt et. al [2] reported that the addition of POME on the shredded oil plam EFB, resulted with 50% volume and mass reduction of the compost heap and 70% reduction in the C-N ratio of the compost materials after 84 days of composting.

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Table 3: Initial and final physical and chemical properties compost materials.

Compost parameter	No. of samples	Average values		Differences, %
		Day 1st	Day 84th	
Temperature, °C	20	62.33	43.08	-30.9
Oxygen concentration, %	20	14.50	18.18	+25.4
Moisture content, %	20	57.30	75.41	+31.6
Bulk density, kg/m^3	20	212.80	322.14	+51.4
Volumetric reduction, %	20	0	47.70	-47.7
C-N ratio, proportion	20	66.03	29.34	-55.6
Nitrogen content, %	20	0.88	1.70	+93.2
Phosphorus content, %	20	0.18	0.28	+55.6
Potassium content, %	20	2.16	5.64	+161.1

CONCLUSIONS

A self-propelled compost turning machine for windrow composting oil palm EFB has been successfully designed, developed, and evaluated by the team of researchers at the Department of Biological and Agricultural Engineering, Universiti Putra Malaysia. A 60 kW@2200 rpm 4 cylinder diesel engine was used to operate 3 individual hydraulic pumps to drive four traction wheels, rotor and blade assembly and power steering system. The machine has overall size of the machine of 3.6 m width X 1.8 m length X 3.1 m height and a total weight of 3.83 ton. The developed compost turning machine was designed to work on a windrow compost heap having size not greater than 2.5 m width 1.5 m height. The conducted turning operation on oil palm EFB compost showed that the machine system was able to give a mass throughput capacity of 84.83 ton/hr (or an equivalent rated compost mass production of 47.29 ton/hr) with a wheel slippage of 36.87% and engine fuel consumption of 5.05 l/hr when operating at a rated travel speed of 280.08 m/hr. The current adopted composting technology on pre-pressed and preshredded oil palm EFB was able to produce a compost with C-N ratio of 29.34, bulk density of 322.14kg/m^3, moisture content of 75%, nitrogen content of 1.70%, phosphorus content of 0.28% and potassium content of 5.64% afer 84 days of composting period.

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