

APPLICATION OF SERIAL SELF-TURNING REACTOR SYSTEM (STR) TO SEWAGE SLUDGE COMPOSTING

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Abstract

This research is an action research following on from a joint-research project on composting technology. The objective of the study is to apply a new composting technology called a serial self-turning reactor system (STR) which was originally developed for municipal solid waste treatment to be used for sewage sludge composting from a wastewater treatment plant. A series of lab-scale and plant-scale STR experiments was performed at Thammasat University's Rangsit campus. All experiments were comprised of sewage sludge (as a substrate), woodchip, and recycled compost (as an amendment). The lab-scale experiment was separated into 12 ratios of sewage sludge, wood chip, and recycled compost, i.e. 1:0.25:0, 1:0.25:0.25, 1:0.25:0.5, 1:0.25:1, 1:0.5:0, 1:0.5:0.25, 1:0.5:0.5, 1:0.5:1, 1:1:0, 1:1:0.25, 1:1:0.5, and 1:1:1 with an aeration rate of 0.25 L/min/kg. The results of the lab-scale experiment indicated that the ratios of 1:1:0.25 and 1:1:0.5 were the optimal mixing conditions for STR composting because these ratios can improve the reheating potential more than the other ratios that met the Thai organic fertilizer criteria. The result of the final study has found that the ratio of 1:1:0.25 is the most suitable mixing ratio for sewage sludge composting using the STR technology because the amount of sewage sludge that can be treated in 1 cycle is more than for the ratio of 1:1:0.5 (being more economical) and the composting performance is better as well. The final products of the STR are compatible with the Thai organic fertilizer standard. The major nutrients of the 1:1:0.25 ratio for planting, namely total nitrogen, available phosphorus, and total potassium had average contents of 2.17, 2.08, and 0.71, respectively. The results for the chemical properties of both the lab-scale and STR experiments are not much different. From this study, the STR has been shown to be an effective system that can be applied with other substrates beyond wood waste (which the STR was originally designed for) without requiring any minor or major modifications. Moreover, the composting cycle can be completed within 2 weeks which was considered as a quick enough composting cycle time.

Keywords: BioMY-BOX, aerated bio reactor, sewage sludge treatment, composting

Introduction

Sewage Sludge in Thailand has increased steadily during the last decade. Bangkok covers more than 1500 km² and has around 10 million inhabitants. The disposal of

wastewater is creating huge problems of pollution. About 108 tonnes of dry matter per day of refuse was generated across Bangkok in 2005. The government spent more than 600

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million U.S. dollars between 1991 and 1998 for construction of new central wastewater treatment plants (BMA, 1995). The amount of sewage sludge is still increasing year by year due to the expansion of Bangkok city but the disposal space is limited and the cost for disposal is projected to increase. This will lead to additional environmental problems unless means are developed for the disposal or use of the sludge material. Many communities use the air-dried or compost methods but these methods still have a problem with the odor in the surrounding areas, while some of the communities dispose of sludge by dumping it with other waste which is considered as an unsuitable way; therefore, composting is an appropriate alternative for waste management (Kanat *et al.*, 2006). Composting not only helps to solve the problem of waste disposal, but also produces a useful bioamendment agent (compost) (Banegas *et al.*, 2007). Sewage sludge from municipal treatment plants is a good candidate for composting and for agricultural purposes (Akhtar and Malik, 2000), but there are many factors that affect the composting process, such as the proportions of the mixture, the aeration rate, oxygen consumption rates, composting recycling, moisture content, pH, carbon/nitrogen, and so on (Golueke and Diaz, 1996). The composting process is considered to be one of the best management methods to stabilize different organic wastes including sewage sludge. Thammasat University (TU) Rangsit campus has been innovating and developing the organic wastedisposal system called Serial Self-turning Reactor System (STR) as an organic preliminary MSW treatment system since 2005. Because sewage sludge is one type of MSW which is considered as an organic waste, it leads us to study the possibility of sewage sludge composting with the STR and extending the applications of the STR to reduce the cost of waste disposal so that it becomes a concept technology for other communities and local administrations to apply this technology for use within their communities according to the local decentralization plan in Thailand for year 2007; this

considered that wastewater treatment and sludge disposal are one of the public utilities that the government must provide for citizens and that the government devolve the responsibility to the local administration in the near future.

Materials and Methods

STR Composting Method Technology

The STR consists of vertical aeration-type reactors and sets of self-turning units. These 2 components are connected vertically making a series of composting and turning processes in alternate sequences. The reactor is assembled with several vertical reactor clusters for adjusting the total reactor capacity. It contains vertical aeration through perforated pipes and an odor venting passage. The reactor doors' mechanism located at the bottom of each reactor is installed for controlling the composted mass flowing through the self turning units below. The doors are able to be closed and opened to adjust the period of composting in the reactor.

The self-turning units are next below the reactor in a unit called BioMY-BOX. It contains no mechanical hardware but only complicated passages to direct flows of different types of material falling down and impacting the unit walls due to gravity, which results in the mixing process of the loaded material. The mixture of the compost material will firstly be loaded into the topmost reactor. After the composting period in the reactor is over, the composted mass will be passed to the adjacent self-turning unit and then the next reactor below in consequential order. After the compost mass has passed through all the unit sequences, the compost product will be obtained.

The STR unit in the prototype system contains reactor fermentation and a parallel turning unit (using BioMY-BOX). Its function is the fermentation of the input compost mass from the top. The reactor is aerated by a number of vertical compressed air dispensers. Supplying compressed air using the vertical

dispensers ensures a low possibility of clogging the air holes, which can much reduce the maintenance cost. After 1 batch of fermentation, the fermented mass will be passed out to the next unit below using only its own weight (gravitational force) (Bongochgetsakul *et al.*, 2006).

There are 2 parallel reactor towers in this pilot operation; each tower contains 2 reactors used for fermentation of the compost mass. The reactor is a cubic shape with total dimensions of 1300 × 1300 × 1000 mm. It is made of stainless steel and PVC. In the upper part, there are some hanging points for the air dispenser pipes. At the bottom of the reactor, there are 5 rotating doors that can rotate simultaneously in the same direction in order to control the flow of compost mass to the lower unit that is used for turning purposes. The turning unit (located between the upper reactor and lower reactor), is called BioMY-BOX, and can be used for turning as well as mixing. This mixing mechanism is the core component of the new technology. It has many important roles in supplying oxygen, redistribution of waste products generated by bacteria, redistribution of the anaerobic zone, temperature, water content, etc. It enhances and reactivates the degradation processes after turnover. The BioMY-BOX is an improvement from a vertical mixing unit called MY-BOX. This mixing method requires no energy supply except potential energy (gravitation). In addition, it requires a very short time in the mixing process to pass through the series of mixing units (Bongochgetsakul *et al.*, 2006).

For the air supply system, air is supplied to each reactor through vertical air dispensers. The pressurized air compressor is regulated by a pressure regulator; the compressed air dispensers are hung from a top horizontal rod at the topmost of the reactor and laid in the same direction as the material flow.

For the compressed air system, the air compressor with a capacity for supplying 96 liters per minute with approximately 0.5 MPa has 1 function in supplying air to the reactor. The pressure of the air is controlled by a pressure regulator. The working pressure is

regulated to approximately 0.3-0.4 MPa. The flow rate of the compressed air entering the reactor is measured by a floating-ball flow rate meter with a capacity of 100 liters per minute.

For the electrical system, the power supply for driving the 110V electrical equipment (this equipment is from Japan), mainly a high-pressure blower and air compressor, is distributed by 300V capacity flexible power lines from a transformer having a capacity of 20k VA.

For measurement of the temperature, a Thermocouple type T is used with a resolution of 0.1°C.

Configuration of reactors and turning unit contains is reactor1, BioMY-BOX, reactor 2, respectively from the top.

All starting material (sewage sludge, wood chip, or garden waste) is weighed for water content and put separately into a bucket. The material in the bucket is thrown onto a bucket conveyor to transport the starting materials into 4 units of the BioMY-BOX mixer; after the starting materials have been mixed, and they are put together into a small bucket. Then the bucket is thrown onto the bucket conveyor again to transport our mixture vertically to the top of the first reactor.

After the first fermentation, the doors of the first reactor are rotated alternately to let the compost mass fall into a turning unit slowly to prevent instant clogging of the mixer cell, and it then passes through the BioMY-BOX mixer to increase the oxygen in the mixture in order for it to referment in the second reactor below. The doors are rotated slowly to gradually pass the compost mass from the first reactor to the mixer. No clogging in the mixer has been observed. During turning, the compost gradually falls into the second reactor and a large amount of ammonia is detected. The ammonia is released from the compost mass while passing through the BioMY-BOX.

Composting Materials

Sewage sludge from Chatuchak wastewater treatment plant in the Bangkok administration area was used in this study. The sewage sludge

that was collected had a physical characteristic similar to a soil with an odor and contained a lot of moisture, so the moisture content was reduced by using the air-dried method. The wood chip (WC) used in this study as a bulking agent came from shredded scraps of routine landscape work at TU. The recycled compost (RC) was used as one of the composting amendment bulking agents to reduce the amount of WC used in the compost pile. Moreover, the reason that we have to use RC in our pile of compost is because the SS contains no activated bacteria, whereas the RC does; therefore, the different varied ratios of the 2 amendment bulking agents were performed in this study. Before mixing all 3 materials we have to analyze the moisture content of the air-dried sewage sludge, wood chip, and recycled compost. After the moisture content has been analyzed we will calculate the additional water

for controlling the initial moisture content to be 55% which is considered as the ideal moisture content for initial composting. Normally, the air-dried sewage sludge contains a moisture content between 30-40%. A computer program has been used for calculating the additional water by providing the moisture content and amount of materials used at each time of composting. Table 1 shows the characteristics of the mixing materials.

Composting Method

In order to perform the STR composting, the necessary lab-scale experiments are performed to identify the degradation of composting of each ratio. Then, the STR composting will be performed after analysis of the lab-scale degradation by using the same conditions as the lab-scale composting. Therefore, the different ratios of SS, WC, and

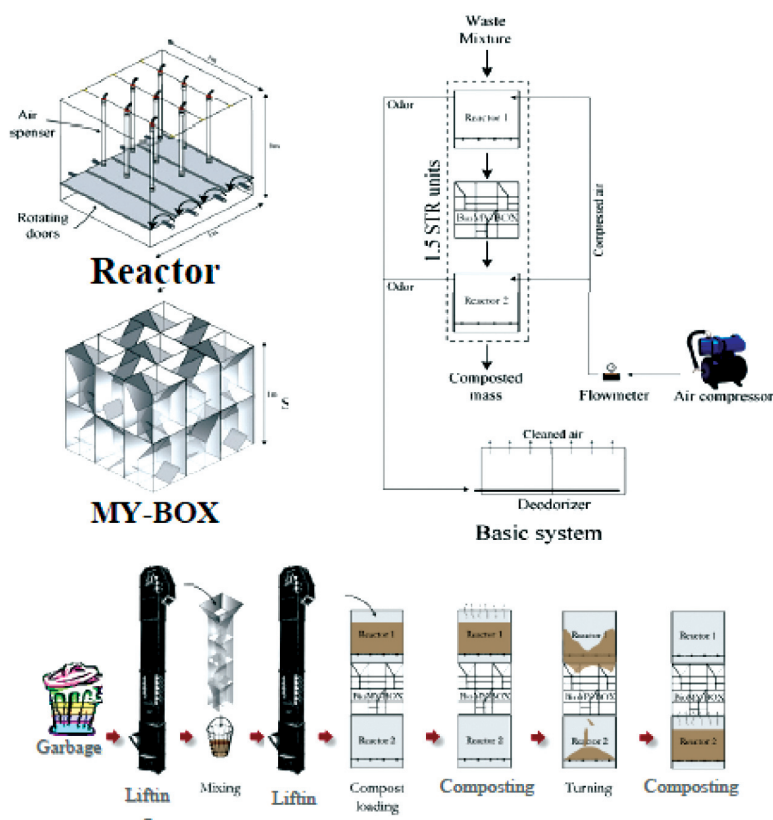


Figure 1. Schematic illustration of overall operations

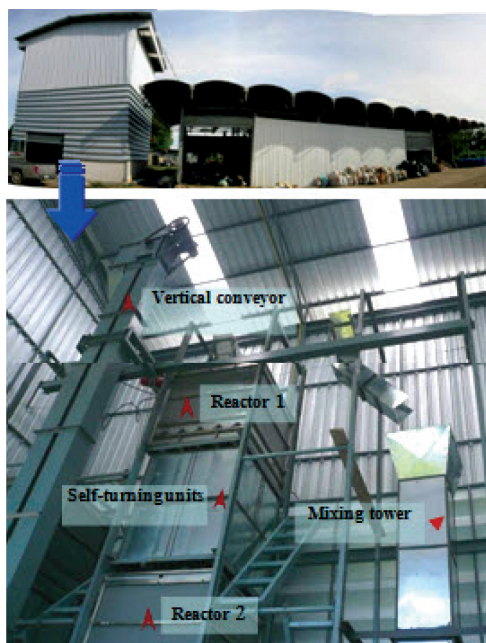


Figure 2. The demonstration pilot-plant and STR composting units at TU

RC are mixed for the lab-scale composting. From a study of the composting of dairy manure with rice straw, Li *et al.* (2008) reported that an aeration rate of 0.25 L/min kg was capable of achieving the highest composting temperature. Therefore, we decided to use a forced aeration rate of 0.25 L/min kg in each case.

The lab-scale SS, WC, and RC were mixed in a galvanized steel box measuring $0.45 \times 0.45 \times 0.45$ m and insulated with foam and each box had an air supply tube attached with a flow gate and regulator to control the air and pressure rate. A Thermocouple was installed at the middle of the compost box to measure and record the change in temperature occurring inside the compost box. The mixture ratios are shown in Table 2.

For the STR scale composting the mixing ratios were chosen from the lab-scale ratios based on the composting performance and the Thai fertilizer criteria by choosing the best

Table 1. Characteristics of mixing materials

Parameter	Raw sewage sludge	Wood chip	Recycled compost
Organic matter (%) or Organic carbon (for wood chip) (%)	26.72	49.19	44.475
Moisture content (%)	56.51	44	53.24
pH	6.23	6.14	6.67
C/N ratio	5	81	12.5
Electric conductivity (dS/m)	4.27	-	2.74
Total Nitrogen, N (%)	2.83	0.61	2.07
Total Phosphorous, P (%)	3.56	0.13	1.78
Total Potassium, K (%)	0.42	0.25	0.91
Arsenic, As (mg/kg)	7.25	-	7.03
Cadmium, Cd (mg/kg)	2.45	-	0.85
Chromium, Cr (mg/kg)	142.25	-	64.35
Copper, Cu (mg/kg)	309.75	-	115.5
Lead, Pb (mg/kg)	83.01	-	26.15
Mercury, Hg (mg/kg)	0.99	-	0.78
Total Bacteria (colony/g)	ND	-	840-2750
Total Coliform Bacteria, TCB (MPN/g)	92	-	1840
Fecal Coliform Bacteria, FCB (MPN/g)	92	-	1840
Salmonella spp. (/25g)	ND	-	ND

Characteristic	Experiment 1				Experiment 1				Experiment 1			
	1:0.	1:0.	1:0.2	1:0.2	1:0.5:0	1:0.5:25	1:0.5:0.5	1:0.5:1	1:1:0	1:1:0.25	1:1:0.5	1:1:1
Ratio	1:0.	1:0.	1:0.2	1:0.2								
SS:WC:RC (v/v)	25:0	25:0.25	5:0.5	5:1	1:0.5:0	1:0.5:25	1:0.5:0.5	1:0.5:1	1:1:0	1:1:0.25	1:1:0.5	1:1:1
Aeration rate (L/min kg)							0.25%					
Initial moisture							55%					
Humidity							85%					
Turning requirement						At day 7 of the composting						
Composting duration						14 days						

1:1:0.25, 1:1:0.5, and 1:1:1 SS:WC:RC mixtures in the thermophilic phase on day 0.9, day 1.1, day 2.7, and day 2.7, respectively (Figure 6). However, to identify composting performance is quite difficult sometimes so, for the evaluation of the reactor simulation performance, we proposed that a quantitative assessment of a temperature–time profile may be made by using: (i) the area bounded by the temperature curve and selected baselines, (ii) the time for which baseline temperatures are equaled or exceeded, and (iii) the times taken to reach peak temperatures. Both 40°C and 55°C are useful reference temperatures, indicating the extent of thermophilic activity and exposure of material to recommend disinfection conditions, respectively (Mason and Milke, 2005). The highest value of A_{40} occurred at the case of 1:0.5:1, which means this mixing proportion has the highest bio-degradation rate. The values of A_{40} of each case are shown in Table 3

The Nutrient Determination of Lab-Scaled

The nutrient determination can represent the quality of the final compost. It can classify the compost product into fertilizer, soil conditioner, or nothing. In this study the nutrient determination will be compared with the Thai fertilizer criteria. The nutrient determinations of each case are shown in Table 4.

From the nutrient determination, there are only 4 cases which satisfied all of the fertilizer criteria; these were case no. 5 (1:0.5:0 SS:WC:RC), case no. 9 (1:1:0 SS:WC:RC), case no. 10 (1:1:0.25 SS:WC:RC), and case no. 11 (1:1:0.5 SS:WC:RC), so these 4 cases can be classified as a fertilizer and the other cases can be classified as a soil conditioner. Electrical conductivity and pH seem to be a problem with many cases that did not satisfy the criteria. Every case passed all of the N, P, and K criteria which are the main nutrients that plants need for growing.

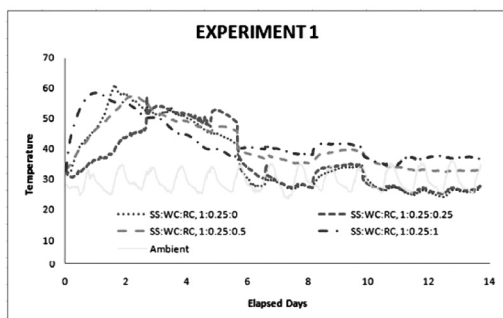


Figure 3. Conceptual of A_{40}

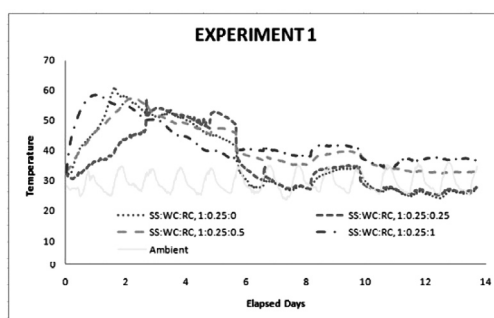


Figure 4. Shows the temperature profiles of experiment 1

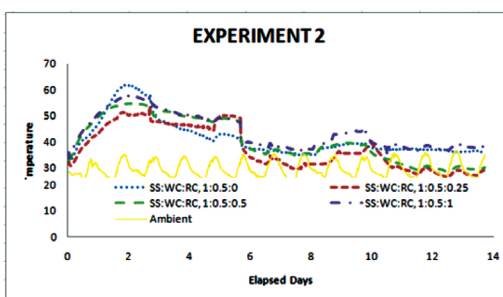


Figure 5. Shows the temperature profiles of experiment 2

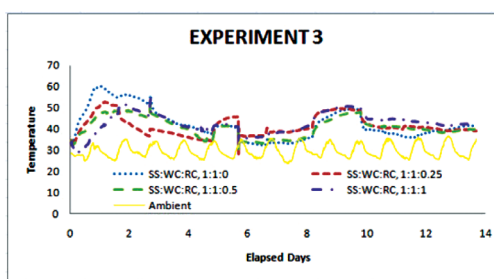


Figure 6. Shows the temperature profiles of experiment 3

Conclusion of Lab-Scaled Composting

From the lab-scale results, we can conclude that RC can improve the reheating potential of the pile of compost after turning but it does

not improve much in the earliest stage of the composting. The peak temperature of each experiment occurred in the case where no RC was added in the composting ratio because

Table 3. Value of A_{40}

Experiment no.	Case no.	SS: WC: RC (v: v: v)	A_{40} (days- °C)
1	1	1:0.25:0	52.95
	2	1:0.25: 0.25	39.14
	3	1:0.25:0.5	50.94
	4	1:0.25:1	52.25
2	5	1:0.5:0	45.60
	6	1:0.5:0.25	37.66
	7	1:0.5:0.5	55.09
	8	1:0.5:1	66.33
2	9	1:1:0	54.22
	10	1:1:0.25	32.63
	11	1:1:0.5	29.44
	12	1:1:1	49.33

Table 4. Nutrient determination

Properties	Thai Criteria	Case number											
		1	2	3	4	5	6	7	8	9	10	11	12
		1:0.25:0	1:0.25:0.25	1:0.25:0.5	1:0.25:1	1:0.5:0	1:0.5:0.25	1:0.5:0.5	1:0.5:1	1:1:0	1:1:0.25	1:1:0.5	1:1:1
Organic matter (%)	> 30	35.11	36.62	36.73	41.53	40.63	43.83	43.53	46.99	47.60	51.34	52.35	53.22
Moisture content (%)	≤ 35	31.2	30.6	31.95	31.02	31.45	32.34	31.12	30.04	30.56	32.40	32.56	31.12
C/N	< 20:1	9	9	10	12	12	11	12	13	13	14	15	16
N (%)	> 1	2.32	2.29	2.10	2.06	2.00	2.21	2.09	2.03	2.05	2.15	2.08	1.89
P (%)	> 0.5	3.22	3.10	2.94	2.61	2.79	2.75	2.68	2.71	2.61	2.34	2.22	2.32
K (%)	> 0.5	0.61	0.52	0.63	0.55	0.58	0.63	0.55	0.61	0.55	0.67	0.55	0.49
pH	5.5-8.5	5.37	5.26	5.35	5.48	5.99	5.50	5.71	5.49	6.25	5.55	5.79	5.15
EC (dS/m)	< 6	7.69	7.31	7.36	6.81	5.29	6.85	6.23	6.02	3.84	5.37	4.90	4.55

* Thai criteria is obtained from Land Development Department

substrate concentration is the parameter that specifies the peak temperature and the heat capacity. If we consider only the temperature profile, the best 2 degradation rates would be case no. 8 (1:0.5:1 SS:WC:RC) and case no. 7 (1:0.5:0.5 SS:WC:RC), respectively. However, both cases could not satisfy the Thai fertilizer criteria. Therefore, the optimal ratios for the STR composting by using SS as a substrate were the ratios of case no. 10 (1:1:0.25 SS:WC:RC) and case no. 11 (1:1:0.5 SS:WC:RC) which passed all of the fertilizer criteria and also improved the reheating potential after pile turning which was suitable for the STR technology which has the advantage in the pile turning process.

Results and Discussion of STR Composting

Physical Properties of STR Composting

From lab-scale composting results, only 4 proportions have passed the Thai fertilizer criteria; therefore, we consider that the mixing ratios of 1:1:0.25 and 1:1:0.5 are the optimal mixing ratios for the STR. The reason is that these ratios can improve the reheating potential, which is considered as an important process of the STR composting, more than the mixing ratios of 1:0.5:0 and 1:1:0. Figure 7 shows the temperature profile with time varied by ratio. Temperature was used as a key factor to determine the steady stage of composting (Trautmann, 1996). The variation of temperature on the graph was a temperature which was measured every 10 minutes for 2 weeks. At the first 2-3 days of the composting, the temperature increased rapidly and reached the highest temperature of 72.6°C for 1:1:0.5 at day 1.7 of the composting, and 74.5°C for 1:1:0.25 at day 3.5 of the composting. Thereafter, the temperature of the compost for the 1:1:0.5 mixing ratio decreased gradually and re-heated again after pile turning at the 7th day of the composting, unlike the 1:1:0.25 mixing ratio that maintained the compost temperature around 70°C before pile turning occurred.

The Nutrient Determination of STR

The results will be compared with the Thai fertilizer criteria to see whether our final composts are fertilizer or not. The final compost that passed all the criteria range can be called fertilizer but if it did not pass even one criteria it will be considered as a soil conditioner only. The physical and chemical characteristics of the compost were observed thoroughly for 3 weeks and the properties of the final compost were determined. A sample of each ratio was collected in 3 samples from different spots, i.e. top, middle, and bottom of the composting pile. Table 5 shows the comparison of the STR composting results and the Thai fertilizer criteria. From the Table it is obviously seen that every mixing ratio passed all of the criteria range so that the final product can be called a fertilizer.

Conclusion of STR Composting

From this study, we can conclude that the ratio of 1:1:0.25 was the suitable mixing ratio for the STR composting system because the amount of sewage sludge that can be treated in 1 cycle is more than the 1:1:0.5 ratio. If we considered it only in an economics way, we will get more product (fertilizer) through 1 composting cycle. Furthermore, if we considered it only on nutrient content, the ratio of 1:1:0.5 seems to be the best ratio because it has much more nutrients in N, P, and, K which are considered as important nutrients for plant growing. Nevertheless, the result of this study could not refer and be specific to all sewage

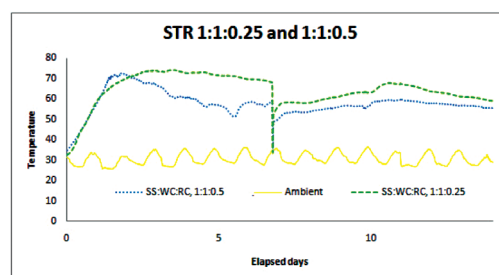


Figure 7. Temperature profiles of ratios of 1:1:0.25 and 1:1:0.5 during the composting

sludge due to the physical properties of each type of sewage sludge from each wastewater treatment plant not being the same. Table 6 shows a general aspect of the STR and other composting technology.

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Table 5. The comparison of STR composting results with Thai fertilizer criteria

Properties	Criteria	STR compost mixing proportions							
		1:1:0.25				1:1:0.5			
		Sample 1	Sample 2	Sample 3	Average	Sample 1	Sample 2	Sample 3	Average
Moisture content	< 35% w/w	22.43	32.89	30.16	28.49	23.56	33.41	31.37	29.44
Organic matter quantity	> 30% w/w	55.28	57.12	57.26	56.55	39.66	59.45	58.35	52.48
pH	5.5-8.5	6.19	6.31	6.17	6.22	6.16	6.00	6.17	6.11
C/N ratio	< 20:1	15	14	15	14.66	11	15	14	13.33
Electrical Conductivity	< 6 dS/m	3.04	3.25	3.15	3.14	4.35	4.08	4.24	4.22
Nitrogen	> 1%	2.08	2.29	2.16	2.17	2.12	2.31	2.41	2.28
Phosphorus	> 0.5%	2.34	1.93	1.98	2.08	2.73	2.12	2.03	2.29
Potassium	> 0.5%	0.78	0.68	0.68	0.71	0.89	0.74	0.80	0.81

Table 6. General aspect of composting technology

	Windrow	Static pile	STR
Land requirement	High	High	Low
Capital cost	Generally low	Generally low for small system	High
Operation cost	Generally low	Low	Low
Skill requirement	Generally low	Generally low	Moderate
Operation control	Turning frequency Amendment mixing	Aeration	Aeration Turning frequency Amendment mixing
Control of air	Limited	Complete, but air channeling	Complete
Control of odor	Depends on feedstock Large area source	Large area source, but can cover	Potentially good
Sensitivity to weather change	Sensitive	Demonstrated in wet & cold weather	Demonstrated in wet & cold weather
Potential operation problem	Susceptible to adverse weather	Control of aeration	Mechanically complex

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