Low C/N Ratio Composting of Excess Sludge from Activated Sludge Wastewater Treatment System of Concentrated Latex Industry

Wanrudee Wanseng[1*], Somtip Danteravanich[2,3] and Panalee Chevakidagarn[1,3]

Abstract

This article presents an experimental result of low C/N ratios with ranges of 3.2:1 to 5.9:1 of composting of excess sludge from activated sludge wastewater treatment systems of concentrated latex factories. The composting experiments were investigated based on test conditions of different compost materials used, with aeration and with no aeration, as well as with seeding and without seeding. In addition, the investigation on the possible use of the obtained compost products as fertilizer on plant growth was conducted. The results indicated that composting was not reached in the thermophilic and mature phases. The slow decomposition of OC occurred during 90 days composting. Loss of N was significantly determined, in particular in the aerated composting units, but K increment was observed. The results indicated that the composting of mixtures of excess bio-sludge, ash, and coconut husk with and without seeding and aeration made compost products compliant with Thai organic fertilizer standards, especially in terms of pH, P_2O_5, K_2O, As, Cd, Cr, Cu, Pb, and Hg. With the results tested on plant growth, the possibility of the use of compost products as fertilizer as experimented with marigolds, illustrated that compost products from a mixture of excess bio-sludge, ash, and coconut husk with seeding and aeration had potential to be used as fertilizer which was equivalent to 15:15:15 chemical fertilizer, in particular in terms of plant height increase rate and numbers of flowers achieved.

Keywords : Concentrated latex industry, Activated sludge waste, Composting, Sludge management

[1] Faculty of Environmental Management, Prince of Songkla University, Hat Yai Campus, Songkhla, Thailand, 90110.

[2] Faculty of Science and Industrial Technology, Prince of Songkla University, Surat Thani Campus, Muang, Surat Thani, Thailand 84100.

[3] National Excellence Center for Environmental and Hazardous Waste Management-Satellite Center at Prince of Songkla University

[*] Corresponding author, E-mail: pook024@hotmail.com Received 29 June 2017, Accepted 7 August 2017

1. Introduction

In 2016, it was reported that there were 106 concentrated latex factories in Thailand and 68 of them were located in 10 provinces in the South of Thailand [1]. This type of rubber factory was known to generate a large amount of wastewater with high strength organic matter. As a result, the most common aerobic wastewater treatment technology used in the concentrated latex factories in the South was the activated sludge system, in particular in the factories located in places where available land was limited and surrounded by communities [2-4]. It was recently reported that 29 concentrated latex factories from the 68 factories in southern Thailand (43%) used activated sludge process (data in 2014) [5] whilst there were only 5 factories (9% of the concentrated factories) which were using this wastewater treatment system in 2002 [4]. This reflected activated sludge system has been increasingly used in the concentrated latex factories in the South of Thailand.

The activated sludge system is a biological wastewater treatment process using acclimated biological flocs to oxidize soluble and colloidal organic matters under aerobic conditions to H_2O, CO_2 and more cells. It is a process to convert dissolved and colloidal organic materials in wastewater into flocculant and settleable microorganisms [6]. The microorganisms finally turned into excess bio-sludge and needed to be well managed in order to control waste sludge pollution problems. If activated sludge systems were used more in the concentrated latex factories in the South of Thailand, the excess biological sludge from the factories would have increased more. The management of excess bio-sludge/solids from activated sludge treatment systems is an increasing financial problem for the factory owners. In addition, sludge management authorities have had to strictly control the industry further [7]. However, dewatered sludge characteristics were studied and reported showing that it had high moisture contents (average value of 88.5%). The average value of organic matter in the sludge was 47%, dry basis. Moreover, the sludge contained high concentrations of plant nutrients in terms of N, P and K. The range values of N, P, K in the excess bio-sludge were reported to be 1.8-11.5%, 0.87-4.5% and 0.56-2.5% dry basis, respectively, or to be equal to the average values of 8.0%, 2.0% and 1.0%, dry basis, respectively. It was illustrated that although the sludge contained N, P, K, the K value in the sludge was less than N and P. It was also noted that this bio-sludge had a very low C/N ratio with range values of 2.1-13.5 or with an average of 4.7 and high N values found in some excess bio-sludge samples caused by the polyacrylamide polymer utilized in the process of sludge conditioning before sludge dewatering [8]. These chemical characteristics reported were consistent with the study of

Chevakidagarn et al., 2011 [9]. They reported that the excess activated sludge from the concentrated latex factories consisted of average values based on dry basis of 40.45% organic matter, 2.93 % N, 6.88 % P_2O_5 and 1.88% K_2O [9]. From this information, it was recognized that this excess bio-sludge may be utilized, in particular, for plant nutrients recovery/recycling.

In addition, composting is a cost-effective technology and quite simply converts organic waste to be soil-like byproducts or to an organic fertilizer. This technology may be an alternative to applying excess bio-sludge from activated sludge wastewater treatment from the concentrated latex factories. Besides, from the literature review of this bio-sludge utilization based on plant nutrients recovery/recycling, it was found that Chantip et al., 2015 [10] had studied the co-composting of the excess bio-sludge from concentrated latex, STR 20 (Standard Thai Rubber 20) sludge and water hyacinth. They experimented with the co-composting under low C/N ratios of 10-15, with aeration and no aeration, and high moisture contents of 67-83% (without moisture control). The results showed that with the composting time of 60 days, the compost products then fully complied with the Thai organic fertilizer standard with the parameters of C/N ratio As, Cr, Cu, Pb, Hg, Cd, P_2O_5, electrical conductivity, pH as well as GI (germination index) [10]. This report reflected that composting of sludge from wastewater treatment plants under low C/N ratios, it was possible to produce quite good compost products, although taking longer composting time. In general, if the C/N ratio of raw compost materials were not adjusted to have the correct proportion of C to N, the best performance of composting would not be achieved, but on the contrary, the used raw compost material could be easily prepared due to without other waste providing and being mixed for C/N ratio adjustment. However, it was found that no experimental evidence supported the composting of excess bio-sludge from activated sludge wastewater treatment systems of concentrated latex factories that dewatered and chemically conditioned process with polyacrylamide. In this study, composting of this dewatered excess sludge without adjustment of the C/N ratio (very low C/N ratio) and moisture (high moisture content) was experimented under aeration and no aeration. Since the K content of the excess sludge was lower than N and P, in the composting experiments, coconut husk and ash were added with the aim of increasing the K content remaining in the end compost product. The experimental study aimed to investigate the possibility of composting and its performance and end compost product quality of excess bio-sludge composting under a very low C/N ratio. Moreover, the compost products achieved were tested for the possibility of being utilized as fertilizer by experimenting on plant growth.

2. Materials and Methods

2.1 Raw Materials used

2.1.1 Composting experiments.

The excess activated sludge used in this experiment was taken from a concentrated latex factory that pretreated sludge by using polyacrylamide polymer in the chemical conditioning process and followed it by dewatering with a belt press. The dewatered excess bio-sludge was used as the main raw material for composting experiments. In addition, the additive materials such as coconut husk were taken from the coconut manufacturing factory and ash was collected from the dried rubber sheet factory. All raw materials were analyzed for basic chemical and physical properties before being used for the experiments according to the procedures described by AOAC [11] and the manual for organic composts analysis of Thailand [12]. Moreover, seeding used in some composting experimental sets was taken from the Land Development Department. It was artificial microbial activator consisting of bacteria, fungi, and actinomycetes. When seeding was used, 100 g of seeding was dissolved in 20 liters of water and kept for 30 minutes before adding it to the compost material layer when setting up the composting unit tested with seeding. The prepared seeding of 20 liters was used in the 1 m^3 of compost materials.

2.1.2 Testing for the possible use of the compost product as fertilizer.

In this testing, Sondang brand hybrid marigolds were used in the experiments. These marigold seeds had a 97% germination rate.

2.2 Experimental set-up

2.2.1 Composting.

In this study, four sets of experimental units for composting of excess bio-sludge were set up. Two sets using only the excess sludge were used for composting under aeration and no aeration. The other two sets were mixed with coconut husk and ash with a mixing ratio of 12:1:2 (V/V) of excess sludge, ash and coconut husk, respectively. These two sets were composted with aeration, whilst one set was added with seeding and the rest had no seeding added. Adding of coconut husk and ash in the composting experimental units aimed to increase the K element contained in the end compost. The initial values of the C/N ratio, P and K, contained in 4 sets of composting units are presented in Table 1. It was found that C/N ratios were very low at a range of 3.2:1 to 5.9:1. The composting experiments were conducted in open channels with dimensions of 0.625 x 1.0 x 1.0 m^3. For each composting unit with aeration, a network of perforated polyvinylchloride (PVC) pipes for air outlets was put at the bottom of the unit and connected to the blower. The air flow rate of 40 m^3/hr was applied to each aerated composting unit. In addition, wood chips sized 2.5 x 2.5 x 7.5 cm^3 were mixed in each composting unit with 30 % (V/V) to increase air voids of the compost materials.

Table 1 Conditions of composting experiments in this study.

Test	Compost materials used and test conditions	Initial C/N ratio	Initial P (% dry basis)	Initial K (% dry basis)
1	Only excess sludge , no aeration	3.7:1	2.14	0.73
2	Only excess sludge, aeration	3.2:1	2.37	0.71
3	Excess sludge + ash + coconut husk: 12:1:2, aeration	5.9:1	1.92	1.87
4	Excess sludge + ash + coconut husk: 12:1:2, aeration with seeding	5.7:1	1.70	1.42

2.2.2 Testing the possibility of using the compost product as fertilizer.

After the composting experiments were finished, the compost products from two composting units that gave the best and second best quality results, in terms of chemical and physical properties, were further investigated for the possibility of being used as fertilizer by testing them on marigold growth. In this experiment, marigold seeds were germinated and grown for 25 days before use to test with the end compost product. After that marigolds were planted in a plastic bag size 25 x 40 cm^2 and used for testing. In all experiments, 4 kg of less fertile soil per bag was used. Table 2 presents the conditions of this experimental step. There were six experimental sets, each set used 5 marigold plants (5 different ones) for testing. All experimental sets were conducted in an artificial greenhouse at the university. It was a control area used for plants growth experiment. It was a semi closed system, having translucent shade of wind and rain, and inside temperatures were similar the ambient outdoor temperatures.

2.3 Samples and Analysis

2.3.1 Composting.

Composting experiments were conducted for 90 days. During the time, no water was added to any of the experimental composting units, and temperatures were measured daily in each composting set. The samples of compost material from each set were randomly and carefully taken on days 1, 5, 10, 15, 30, 45, 60 and 90 of the experiment. From each a sample weighing 500-600 grams was used for physical and chemical analysis in terms of MC (moisture content), pH, ash, OC (organic carbon), N, P, and K in order to follow up the composting performance. The physical and chemical parameters were determined according to the methods described by AOAC [11] and the Manual for Organic Composts Analysis of Thailand [12]. In addition, physical properties such as color, smell and height of the composting pile changing alongside the composting experiment were also observed as described by Polprasert, 2007 [13].

Table 2 Experimental conditions for testing the possibility of using the compost product as fertilizer.

Test Set	Test conditions
T1	Only soil
T2	Soil combined with 5 gram of 15:15:15 chemical fertilizer
T3*	Soil combined with 40 gram of the best quality of the compost product obtained
T4*	Soil combined with 73 gram of the second quality of the compost product obtained
T5**	Soil combined with 20 gram of best quality of the compost product obtained
T6**	Soil combined with 36 gram of the second quality of the compost product obtained

Note: * Amount of compost product added were calculated based on N content equivalent to N content in a control experimental set that used a chemical fertilizer.

** Amount of compost product added was calculated based on N content equivalent to a half of N content in a control experimental set that used a chemical fertilizer.

After composting reaction was reached at the end of the 90 day experiment, the end compost products were determined for the percentage of marble and gravel contained in them and also were analyzed for characteristics of pH, MC, conductivity, C/N, OM (organic matter), OC, N, P_2O_5, K_2O, germination index and the 6 heavy metals of Cd, As, Cu, Cr, Pb, and Hg contained in the products. The end compost products' characteristics were determined by following the Manual for Organic Composts Analysis of Thailand [12. The characteristics results of the end compost products were compared with Thai organic fertilizer standards announced by the Department of Agriculture in 2005 [12].

2.3.2 Testing the possibility of using the compost products as fertilizer.

This experimental test was conducted for 60 days. During the experiments, the marigold growth rate was determined in terms of increased height, and number of flowers. This was determined on the 1st, 15th, 30th, 45th and 60th days of experiments. In addition, soil samples from each set at the start and at the end of experiments were analyzed for pH, OM, TN, and P_2O_5 following the methods described by AOAC [11].

For statistical analysis, the average and standard deviations of the sample data obtained were determined and the differences between the experimental sets were tested by a Duncan's New Multiple Range Test at the significant level of 0.05.

3. Results and Discussion

3.1 Composting Experiments

3.1.1 Waste characteristics used in the composting experiments.

Table 3 presents the characteristics of three wastes used in this composting study. It was observed that the excess bio-sludge was rich in MC, VS (volatile solids), OM and TN, whilst ash contained a high content of K and had high pH, but had less MC, VS, N and P. However, coconut husk was found to be rich in organic matter as well as having quite high K content. The characteristics of excess bio-sludge used in this study were similar to the previous reports, as mentioned before [8-9]. Moreover it was consistent with Kritsampan's report. She reported that activated sludge waste from concentrated latex factories consisted of high nitrogen concentrations in the range of 1.0-10.7%, dry basis [14].

Table 3 Characteristics of wastes used in composting experiments.

Characteristics	Excess bio-sludge	Ash	Coconut husk
Moisture content (%)	88.47	4.02	60.59
pH	7.11	10.3	7.4
VS (%, dry basis)	71.70	17.15	94.55
OC (%, dry basis)	29.39	3.59	57.66
OM (%, dry basis)	50.66	6.19	99.42
TN (%, dry basis)	8.55	0.03	0.59
TP (%, dry basis)	1.78	0.13	0.53
TK (%, dry basis)	0.83	3.67	1.64

3.1.2 Composting performance.

The chemical and physical properties of compost materials were determined in order to follow the reduction and increment of those characteristics. The data obtained are presented in Table 4 and Figures 1-2.

It can be seen from Table 4 that the maximum temperature in 4 composting units was about 40 ^{o}C that was not in the thermophilic phase. The thermophilic temperature in compost piles is usually in the range of 50-60^{o}C. This thermophilic range will significantly optimize both the organic substrates stabilization and pathogen inactivation [13]. In this study, all temperature levels in the composting units were observed to be 1-3 ^{o}C higher than the ambient temperature. The temperature levels in the composting units showed increasingly at the beginning of composting, after the temperature reached to the maximum, it fell with the environmental temperature at about 60 days. This reflected that the composting occurred with slow composting reaction or called cold composting.

Table 4 The initial and final values of parameters investigated in composting experiments.

Parameters	Samples/change	Test 1	Test2	Test3	Test 4
Temperature (^{o}C)	Initial	29.3	28.6	30.3	30.7
	Final	28.0	28.0	32.0	36.0
	Maximum	39.6	36.0	37.0	40.0
pH	Initial	7.21	7.06	8.23	8.21
	Final	6.58	6.55	8.05	8.48
Moisture content (%)	Initial	88.09	88.85	84.22	82.99
	Final	70.58	61.00	52.26	47.84
	% change	-19.87	-31.34	-37.95	-47.84
OC (%, dry basis)	Initial	30.27	29.83	28.62	25.08
	Final	27.13	25.73	17.13	13.94
	% change	-10.37	-13.74	-40.15	-44.42
TN (%, dry basis)	Initial	8.13	9.25	4.81	4.36
	Final	5.16	4.03	1.39	2.11
	% change	-36.58	-56.48	-71.19	-51.73
TP (%, dry basis)	Initial	2.14	2.37	1.92	1.70
	Final	1.17	1.39	1.72	1.32
	% change	-45.23	-41.65	-10.04	-22.41
TK (%, dry basis)	Initial	0.73	0.71	1.87	1.42
	Final	1.24	0.88	1.89	1.90
	% change	69.51	22.82	1.01	33.80
C/N ratio	Initial	3.7	3.2	5.9	5.7
	Final	5.3	6.4	12.4	6.6

Note: Test 1: Only excess sludge, no aeration; Test 2: Only excess sludge, aeration

Test 3: Excess sludge + ash + coconut husk: 12:1:2, aeration; Test 4: Excess sludge + ash + coconut husk: 12:1:2, aeration with seeding

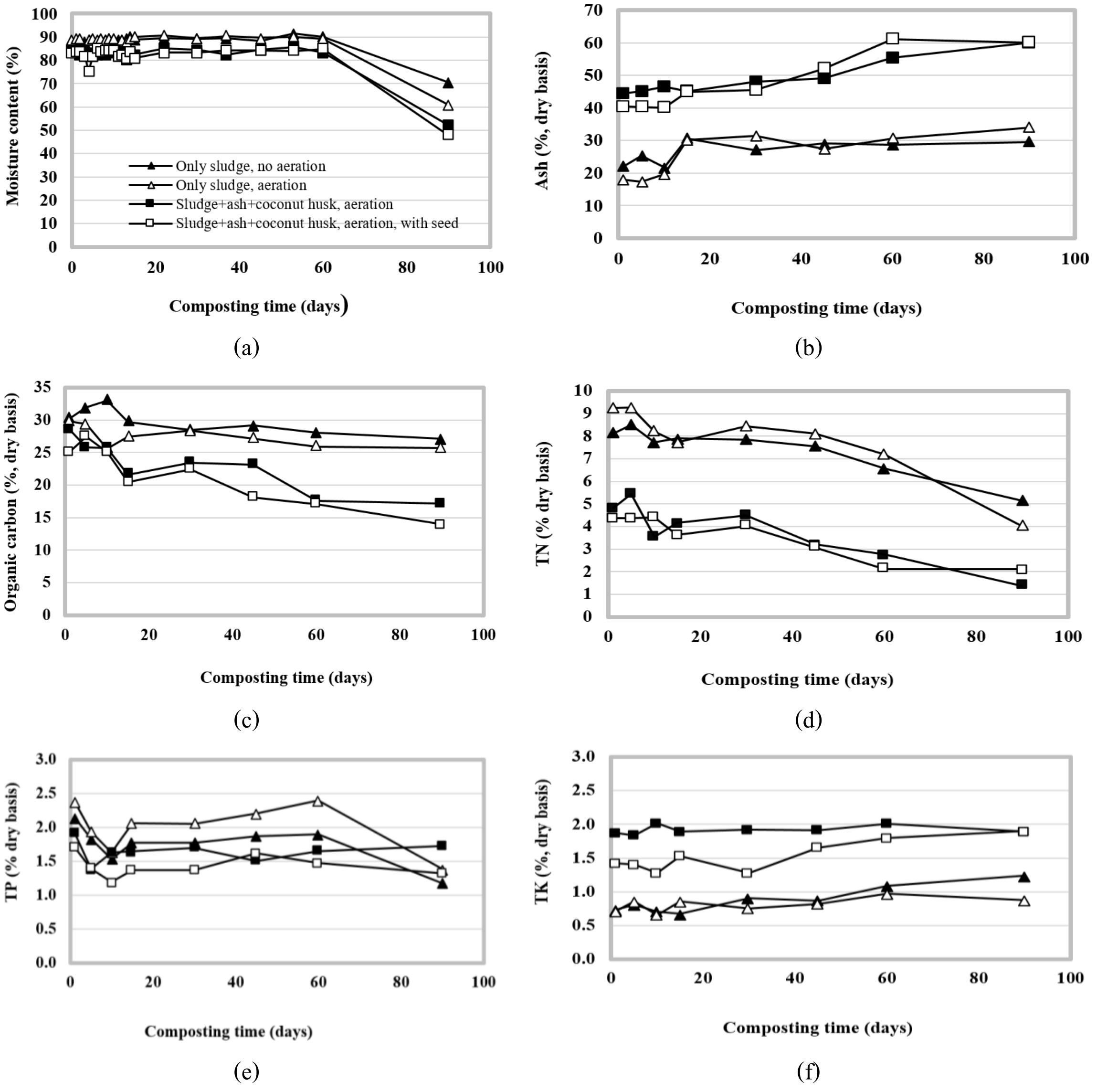

Fig. 1. The profiles of moisture content (a), ash (b), organic carbon (c), TN (d), TP (e), and TK (f) in 4 composting units.

The initial pH of composting units using only excess sludge was neutral, whilst the composting units mixed with ash and coconut husk had a slightly alkaline pH due to ash mixing effects. At the end of composting, the pH of the composting units using only excess sludge changed to slightly acidic, but for the resting units, the pH was still alkaline.

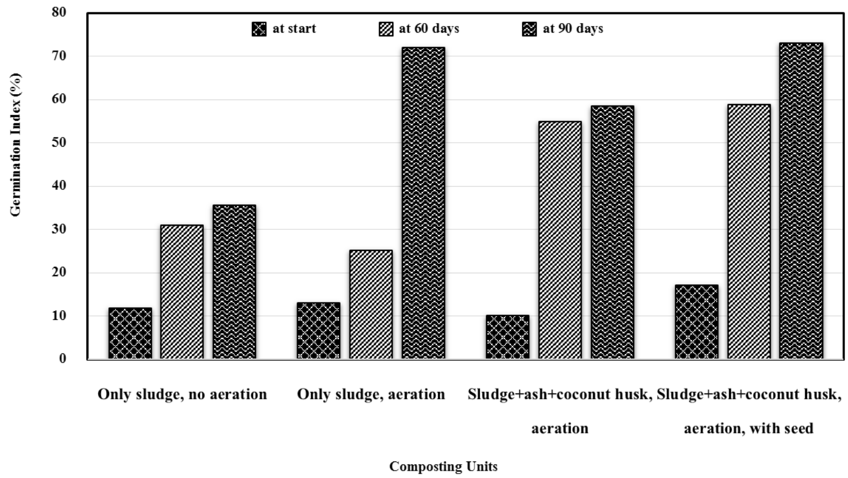

Fig. 2. Germination index changed in 4 composting units.

It was observed that the variations of moisture contents in all composting units changed quite a lot during the day 60 to day 90 of composting time, whilst during day 1 to day 60, the reduction of MC was found not to have changed much. The excess bio-sludge used in this experiment may still contain polyacrylamide (PAM) due to it having been used in the chemical sludge conditioning process. PAM is a polyelectrolyte that neutralizes the surface charge of bio-sludge flocs and generates very large flocs to increase filterability when dewatering sludge. PAM is a long-chained polymer and was reported as being used as a soil conditioner [15]. It was reported that PAM could bind clay particles and formed water-stable aggregates and in case even a small dose of PAM was used, aggregation of large amounts of organic matter could be accomplished [16]. Since bio-solids containing PAM used in this composting study may have been the cause of a lower rate of MC reduction during 1-60 days due to the water-stable forming of sludge that prevents moisture evaporation from the composting materials, although aeration has been using. In addition, Chu et al, 2001 [17] reported that using PAM polyelectrolyte could reduce the density level of microbe in the flocculated waste activated sludge, and also possibly retarding the subsequent biodegradation reactions. It was also reported that PAM was partial degradation by both the conditions of aerobic and anaerobic [18]. Therefore, during 60-90 days of composting, the compost materials as well as PAM might be more degraded and reduced the water-stable property of sludge, consequently quite faster loss of moisture contents than the 1-60 days of composting. In this study, the composting unit with mixed wastes, seeding and aeration gave the highest moisture content reduction, but the composting unit with only excess sludge and no aeration was found to have the lowest moisture content decrease and had the final moisture content at a high level of about 70%. It may have been caused by no aeration. However, MC in composting units with aeration was determined to be at quite high levels, although the composting experiments run up to 90 days.

In addition, the variations of OC, N, P, K and ash were determined as shown in Figure 1. The reductions of OC and N and the increment of ash changed significantly during 30-90 days of composting, but not much during the first 1-30 days. This may have been caused by the latent phase which is time needed for microorganisms to acclimatize in the composting units that had a high moisture content, low C/N ratio and due to the mesophilic phase as in the result of low OC degradation rates in the composting units. This may have been influenced by the initial C/N ratio. In this study, the initial C/N ratio was much lower than the optimal ratios (25 to 30) [13] and was out of the acceptable range, but the C/N ratio in composting units with mixed wastes was found to be higher than the composting units used only bio-sludge. This may cause the composting units mixed wastes to have a higher OC decomposition than the composting units using only bio-sludge. During the composting period, the OC was decomposed by microorganisms become inert material, which is inorganic matter, so that the ash element increased with composting times. All composting units showed the samme trends of ash increment profiles.

However C/N ratios increased very slowly, and after 90 days of composting, it increased from the ranges of 3.2-5.9 : 1 to 5.3-12.4 : 1 which reflected that the composting process had not reached the maturation phase yet. In addition, the decrease of N in all composting units was determined. This indicated that there was a significant loss of N in the composting units. It is generally known that after organic materials in compost piles are degraded, NH_3 is generated and parts of this NH_3 can be lost through volatilization when pH in the compost piles is more than 7. In addition, reduction of N loss in compost piles could be controlled by the adjustment of C/N ratio, aeration and pH in the compost piles [13]. In this study, N reduction in composting units with aeration as well as with initial pH of alkaline was observed to be higher than in the composting units without aeration. This was similar to the results reported by Chantip et al., 2015 [10]. They presented that co-composting of sludge from wastewater treatment plants of concentrated latex and STR20 factories with water hyacinth at low C/N ratios of 10-15 under longer alkaline pH in the composting bins caused more N reduction [10].

With regards to P and K, it was observed that they slightly fluctuated from the start to the end of composting. However, in the 90 days composting, P in composted materials was determined to be lower and K was higher than at the initial composting. This reduction and increment of nutrient contents occurred due to microbial activity. It was noted that K concentrations in the composting units using mixed wastes was determined to be more than 1%, dry basis.

In all composting units, it can be observed that the germination index (GI) increased along the composting time (Figure 2). It was found that composting with only bio-sludge and no aeration had the lowest GI. In 90 days composting, the highest GI was found in the composting unit tested with mixed waste, seeding added and aeration (GI = 73.13 %). GI indicated the maturity of the composting. If composting reaches maturity, the GI should be higher than 80% [19]. From GI results obtained, it could be seen that the composting of 4 units had not reached maturity phase yet. However, compost materials usually consist of some biologically resistant elements, a complete stabilization/ maturation during composting may not be easily achieved. Satisfactory degree of required stabilization/maturity of composting could be gained by providing enough composting time, but also depended on the environmental factors in composting [13]. Moreover, it was noted that studied results of GI in this study was consistent with Guo et al., 2012 [20]. They studied the effect of low C/N ratios on composting and illustrated that C/N ratio affected the maturity of compost. The low C/N ratio gave a low GI value [20]. In addition, during 90 days composting experiments, the collapse of compost materials was significantly determined to be 15-27% of height reduction. Malodor was easily detected during 60 days of composting, although the composting was aerated. At 90 days of composting, in all composting units the black color of compost materials was observed. Also, the composting unit with seeding did not show much performance difference when compared with the composting in which seeding was added. Since the excess bio-sludge used in this study was biomass, a byproduct from the activated sludge. It might have enough microorganisms in particular bacteria, in the bio-sludge used to compost. Addition of seeding consisted of 3 groups of microorganisms of fungi, actinomycetes and bacteria could not promote more biodegradation rate.

3.1.3 Compost product characteristics.

Table 5 presents compost products' characteristics of 4 composting units. It indicates that the characteristics of compost products in the experimental sets using mixed waste were able to comply with Thai organic fertilizer standards [19], in particular in terms of pH, P_2O_5, K_2O, As, Cd, Cr, Cu, Pb, and Hg, but not for N, organic matter, moisture content and electrical conductivity. These four parameters not complied with the standard may be conducted to meet the standard via providing longer time of composting, consequence gave better stability/ maturity degree of the compost product as well as achieved lower moisture content. Overall, it was noted that the composting units in which coconut and ash were mixed in the excess bio-solids produced compost products having K contents to meet the organic fertilizer standards, whilst the composting of only excess bio-sludge could not produce the K element in the compost product to comply with the standard. The samples of compost products from the composting units using the mixture of excess bio-sludge, ash, and coconut husk, with and without seeding and aeration further determined the possibility of utilizing the compost product as fertilizer by testing it on plant growth.

3.2 Testing the possibility of using the compost product as fertilizer on plant growth.

The potential of using compost products as fertilizer was examined by testing them on marigolds. In this experiment, there were 6 tested sets. The compost products used to test in this experiment were taken from the composting units using a mixture of excess bio-sludge, ash, and coconut husk, with and without seeding and aeration. Soil samples taken from the 6 tested units at the beginning and at the end of experiments were determined for pH, TN, P_2O_5 and OM. TN and P_2O_5 in soil samples, after planting marigolds, were observed to decrease due to plant uptake. It was found that marigolds with added compost products (T4) grew equivalently with the test set with chemical fertilizer added (T2). When statistical analysis was calculated to test the data of the average increase height rate of the marigolds and their average number of flowers in tests T2 and T4, it was found that there was no significant difference in these two experimental sets at the significant level of 0.05. This indicated that compost products obtained from composting of the mixture of excess bio-sludge, ash, and coconut husk, with and without seeding and aeration can function as chemical fertilizers for marigold plantations.

4. Conclusion

The excess bio-sludge from activated sludge wastewater treatment systems of concentrated latex factories can be used as raw material for composting to increase the sources of organic fertilizer. Composting of only bio-solids or co-composting of this waste with coconut husk and ash could be conducted at a low initial C/N ratio, but would take a longer time. However, the compost products achieved after 90 days composting could be used as organic fertilizer because they contained N, P, and K that matched organic fertilizer standards. The results obtained indicated the alternative utilization of excess bio-sludge from the wastewater treatment systems of concentrated latex via composting technology. However, it is recommended that further studies be conducted to investigate the best conditions of composting of this excess bio-sludge, as well as the effects of chemical polymer used in sludge conditioning.

Table 5 The investigated results of the compost products characteristics compared with Thai organic fertilizer standards.

Parameters	Thai Organic Fertilizer Standard	Only sludge, no aeration	Only sludge, aeration	Sludge+ash+ coconut husk, aeration	Sludge+ash+ coconut husk, aeration, with seed
Moisture content (%)	$\leq$ 35	70.58	61.00	52.26	47.84
Marble and gravel (%)	$\leq$ 5	ND	ND	ND	ND
Organic matter (%)	$\geq$ 30	13.76	17.30	14.10	12.54
pH	5.5-8.5	6.58	6.55	8.05	8.48
C/N	$\leq$ 20:1	5.26	6.39	12.36	6.62
Electrical conductivity (dS/m)	$\leq$ 6	30.7	28.0	31.9	26.1
Total N (%)	$\geq$ 1.0	1.52	1.57	0.66	1.10
P_2O_5 (%)	$\geq$ 0.5	0.79	1.24	1.89	1.58
K_2O (%)	$\geq$ 0.5	0.44	0.41	1.09	1.19
Germination index (%)	$\geq$ 80	35.69	72.50	58.50	73.13
As (mg/kg)	$\leq$ 50	0.131	0.230	1.117	1.925
Cd (mg/kg)	$\leq$ 5	0.306	0.355	0.773	0.965
Cr (mg/kg)	$\leq$ 300	1.306	1.396	2.041	2.627
Cu (mg/kg)	$\leq$ 500	3.501	5.420	7.586	14.616
Pb (mg/kg)	$\leq$ 500	2.482	3.358	7.283	6.840
Hg (mg/kg)	$\leq$ 2	<LD	<LD	<LD	<LD

Note: LD: less than detection limit, data expressed as wet basis.

5. Acknowledgements

The authors would like to thank the concentrated latex factories in the South of Thailand for giving information and activated sludge waste samples for this study. Besides this, it also thanks the Graduate School in Prince of Songkla University for financial support to conduct this study, and gratefully acknowledge the laboratories in Prince of Songkla University for supporting the equipment for samples analysis. Without this support, the research would not have been possible.

6. Reference

[1] Department of Industrial Works, “Industrial data in Thailand”, Available: http://www.diw.go.th/hawk /content.php?mode=data1search, 28 October 2016. (in Thai)

[2] A. Rakkoed, S. Danteravanich and U. Puetpaiboon, “Nitrogen removal in attached growth waste stabilization pond of wastewater from rubber factory”, Water Science & Technology 40, 1999, pp 45-52.

[3] P. Prabnakorn, “Primary Treatment by Air Floatation in Rubber Trap Tank for Latex Rubber Plant Wastewater Treatment”, Master Thesis, Environmental Management, Prince of Songkla University, Thailand. 2000.

[4] S. Danteravanich, U. Puetpaiboon and N. Proukaew, “A survey of wastewater management in the concentrated latex industry in Southern Thailand”, In: H. Furumai, F. Kurisu, H. Katayama, H. Satoh, S. Ohgaki, and N.C. Thanh (Ed.) “Southeast Asian Water Environment 2”, IWA Publishing. 2007.

[5] Department of Industrial Works, “Industrial wastewater treatment data”, Available: http://reg.diw.go.th/water/data.asp?amp=10&prov=90, 4 January 2015. (in Thai)

[6] Metcalf & Eddy, “*Wastewater Engineering, Treatment and Reuse* (4th Eds.)”, McGraw-Hill Companies, 2003.

[7] The Ministry of Industry, “Announcement of the Ministry of Industry on the Disposal of Unwanted Waste”, Available: http.diw.go.th/diw_web/html/versionthai/laws/00180774.PDF, 10 January 2016. (in Thai)

[8] W. Wanseng, S. Danteravanich and P. Chevakidagarn, “Investigation of Excess Sludge Generated from Activated Sludge Treatment Plant of Concentrated Latex Factories: An Investigative Case Study in Southern Thailand”, Environment and Natural Resources Journal 15(2), 2017, (July- December, 2017), pp 51-61.

[9] P. Chevakidagarn, S. Danteravanich, C. Siriwong and N. Waijarean, “Recycling of Centrifugal Residues and Excess Sludge from Concentrated Latex Factory as Granular Composted Material”, Project report, Faculty of Environmental Management, Prince of Songkla University, Thailand. 2011.

[10] P. Chantip, S. Danteravanich and P. Sutthirak, “Co-composting of sludge from wastewater treatment plants of concentrated latex and STR 20 factories with water hyacinth”, Proceedings of the 1st International Conference on Environment, Livelihood and Service (ICELS), Bangkok, Thailand, 2015 pp. A06001-1 to A06001-11.

[11] AOAC, “*Official Methods of Analysis of the Association of Official Analytical Chemists* (15th Eds.)” AOAC, Inc., 1990.

[12] Department of Agriculture, "*The Manual for Organic Compost Analysis*" Ministry of Agriculture and Cooperatives, 2008. (in Thai)

[13] C. Polprasert, "*Organic Waste Recycling: Technology and Management* (3rd Eds.)" IWA Publishing, 2007.

[14] D. Kritsampan, "Appearance of Tetramethylthiuram Disulfide and Zinc in Wastes of Concentrated Latex Industry", Master Thesis, Environmental Management, Prince of Songkla University, Thailand. 2013.

[15] A.I. Azzam, "Agriculture polymer: Polyacrylamide preparation, application and prospects in soil conditioning", Communications in Soil Science and Plant Analysis 11, 1980, pp. 767-834.

[16] M. De Boodt, "Soil conditioning for better soil management", Outlook on Agriculture 10, 1979, pp 63-70.

[17] C. Chu, D. Lee, B. Chang and C. Liao, "Effects of polyacrylamide on microbial density levels and biodegradability in waste-activated sludge", Journal of Chemical Technology and Biotechnology 76, 2001, pp 598-602.

[18] L. L. Chang, D. L. Raudenbush and S.K. Dentel, "Aerobic and anaerobic biodegradability of a flocculant polymer", Water Science and Technology 44 (2-3), 2001, pp 461-468.

[19] Department of Agriculture, "The Organic Fertilizer Standard", Available: http://www.ratchakitcha.soc.go.th/DATA/PDF/2548/00172707.PDF, 29 January 2016. (in Thai)

[20] R. Guo, G. Li, T. Jiang, F. Schuchardt, T. Chen, Y. Zhao and Y. Shen, "Effect of aeration rate, C/N ration and moisture content on the stability and maturity of compost", Bioresource Technology 112, 2012, pp. 171- 178.