Co-Composting Rubber Factory Waste with other Wastes for Reuse

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Abstract— *The objective of this study is to present the characteristics of the co-compost produced from rubber factory waste and the high nitrogen-containing materials for soil fertilizers. The experiments were performed as batch tests using an aerobic composting for detention time of 60 days [1]. Rubber factory waste constitutes valuable sources of organic matter with high C/N ratio, low moisture content (30-58%) and neutral pH (7.0-8.0). The most important parameter in composting for soil fertilizer is the C/N ratio. Many researchers reported that the optimum C/N ratio for general composting should be 25-35:1 [2]. Due to the high C/N ratio, the evaluated rubber factory waste compost alone was not appropriated to be used as a soil conditioner or fertilizer. In this study, other wastes and materials with high nitrogen content and high moisture content are composted with the rubber factory waste to improve the final product nutrient. The C/N – decomposition of organic matter is brought about by microbial that use the carbon as a source of energy and nitrogen for building cell structure. Microbial that uses the carbon as a source of energy and nitrogen for building cell structure are added in some reactors to study its impact on the decomposition process. Another factor affecting the successful application of compost for agriculture purpose is its degree of stability and maturity [3]. This results show that the co-composted material formed in all the reactors with brown to brownish black color and soil-like texture after the maturation period (60 days). The co-compost from the aerobic reactor provides good humus to build up a poor physical soil and some basic plant nutrients. This co-composted material has the N, P, K and Ca content as nutrient elements which is enough to permit it to be designated a fertilizer in the legal sense. The co-composting in this research proved to be an efficient, environmental – friendly alternative to solve the disposal problems of rubber factory waste and sewage sludge. Finally, the final co-compost can be promoted for fertilizer obtaining by mixing rubber factory waste with sewage sludge from municipal wastewater treatment plan, and water hyacinth.*

Keywords— **Co-composting, rubber waste, reuse, sewage waste, C/N ratio.**

1. INTRODUCTION

A typical rubber factory waste from Standard Thai Rubber (STR20) industry consists of leaves, branch of tree, soil, and stone which came from the rubber tapping process. Thus, it contained a high level of impurities. However, these rubber wastes cannot be discharged freely due to the legal waste management policy in Thailand. Usually, these rubber wastes were used for landfilling in the factory area. However, the amount of rubber factory waste continues to grow. This situation has urged the need to develop and study alternative sustainable waste management technologies such as composting. Composting is an acceptable alternative because it not only reduces the volume of rubber factory waste but also reuses waste for soil fertilizer and produces a residue that can be used for soil conditioning.

Composting is the biological degradation of organic materials under aerobic conditions, leading to the production of final products sufficiently stable for storage and land application without adverse environmental effects [3]. It is the simple and cost-effective technology and also an environmental-friendly technology to treat and recycle organic wastes. During composting, microorganisms break down organic matter in composting material into carbon dioxide, water, heat, and the final compost product. To ensure optimal conditions for microbial growth, carbon and nitrogen must be present in the proper balance in the mixture being composted. The ideal environment for composting consists of (1) the C:N ratio of the composting material between 25:1 and 35:1 [2], (2) the moisture content between 50% and 70%, (3) small particle sizes, (4) adequate oxygen supply, and (5) sufficient void space for air to flow through [4]. The most important parameter for composting is the C/N ratio. A lower C/N ratio can result in ammonia odor. A higher C/N ratio will not form optimal conditions for microbial growth causing degradation to occur at a slower rate and temperature to remain below levels required for pathogen destruction. Phosphorus, calcium and trace quantities of several other elements are all play a part in cell metabolism. The co-composting is required for getting better quality of compost.

The most important factors affecting the compost application for agricultural purposes are its degree of stability and maturity [3]. Since rubber factory waste is a primary source of carbon, it must be mixed with a higher nitrogen-containing material such as sewage sludge, cattle manure, green vegetable, urine, food waste, feces or municipal solids waste. Thus co-composting of rubber factory waste with the higher nitrogen-containing materials seems to be an attractive and viable treatment technology in which the resources in the wastes can be reused and the safe disposal is ensured. Although, many composting experiments were conducted to describe the effects and/or optimal environmental factors including

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temperature, aeration rates, moisture and nutrient contents [5,6]. The influence of the above parameters varies with the composting materials. Moreover, no study has been emphasized on the utilization of rubber factory waste for composting. The implementation of composting of rubber factory waste at the full-scale level has been limited because of the relatively high cost and some technical problems. Thus, this study is a pilot study to experience the idea. The experiments were set up in a batch reactor under aerobic composting condition. The aerobic composting is characterized by a rapid decomposition rate and release of a great deal of energy in the form of heat from the oxidation of organic carbon to carbon dioxide [2]. Additional, it creates no odor problem and the resulting high temperature should be quite effective in reducing the pathogenic potential of the waste material.

The present investigation is focusing to promoting the land application of compost obtained from rubber factory waste and high-containing organic wastes. In order to achieve the goal, the optimum ratio and moisture content of rubber factory waste and other waste are evaluated. Experiments were carried out in a batch reactor.

2. MATERIALS AND METHODS

2.1 Experimental raw materials

Five different materials are used in this study, including ruber factory waste, water hyacinth, dewatered sludge from municipal wastewater treatment plant, dewatered sludge from wastewater treatment plant of seafood factory, and cattle manure. The rubber factory waste was collected from a STR20 industry located at Patthalung city (Southern of Thailand). The dewatered sludges were obtained from Phuket municipal wastewater treatment plant (WWTP) at Phuket city (Southern of Thailand) and a seafood industry at Songkhla city (Southern of Thailand). Table 1 summarizes the physicochemical properties of the rubber factory wastes and other wastes. Note that the rubber factory waste has low moisture content (30-58%), high organic carbon (135 g/kg) and high C/N ratio (around 270:1). Water Hyacinth could be used to adjust the moisture content and C/N ratio of the composting mixture. While, the cattle manure could be used to improve the nitrogen content for the optimum C/N ratio.

2.2 Experimental setup

An aerobic reactor consists of a cylindrical vessel of 60 litres capacity and a mixer handle for turning the compost reactor. A lab-scale study is conducted using the rubber waste with other materials in a batch system. The schematic diagram of the experimental setup is shown in Fig. 1. The total of four reactors were used in these experiments. The initial mixture in each reactor is shown in Table 2.

The mix ratio of mixed wastes was selected based on the calculation of optimum C/N ratio. The reactors were loaded with mixed wastes. To homogenize the mixed waste, any large particle size waste will be cut to approximately 1.3-5 cm in length [2,7]. A fairly small particle size reduces the depth of oxygen diffusion and microbial advance with the particle, aids the homogenizing of material [8]. Experiments were carried out in the batch reactor. The reactor was turned manually everyday to improve the bulk porosity for better aeration. Aerobic composting was carried out in four composting reactors for 60 days.

Table 1. Properties of characteristics of raw wastes for composting

Materials	Moisture content (%)	pH	Organic carbon (g/kg)	Nitrogen (g/kg)	C/N Ratio
Rubber waste	30.0-58.0	7.0-8.0	135	0.50	270
Water hyacinth	90.0-93.5	5.6-6.1	37	2.11	17.5
De-watered sludge from seafood industry	60.5-65.2	7.0-7.5	5.6	0.99	5.6
De-watered sludge from Muni-cipal WWTP	77.0	7.0-8.0	6.4	0.90	7.1
Cattle manure	33.9	7.9-8.2	27.2	1.41	19.3

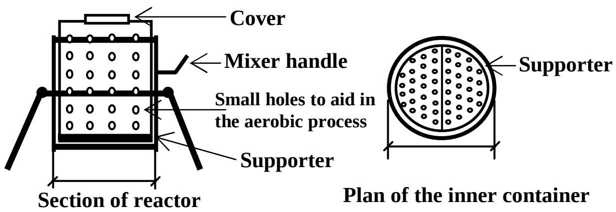

Fig.1. The aerobic compost reactor

Table 2. Prepared mixed wastes for composting

Reactor	Mixed Waste Components
1	50% rubber factory waste + 25% water hyacinth + 25% dewatered sludge from municipal wastewater treatment plant
2	25% rubber factory waste + 25% water hyacinth + 50% dewatered sludge from wastewater treatment plant of seafood factory
3	20% rubber factory waste + 40% cattle manure + 40% water hyacinth
4	50% rubber factory waste + 50% cattle manure

2.3 Performance measures

Characteristics of the mixed waste components were analyzed: moisture content, pH, nitrogen, temperature, TP, organic carbon, organic matter, E. *coli*, Ca, Mg and K before composting. During the composting, the samples were collected and analyzed again however the E. coli was not analized. The performance of the reactor was monitored every 4 days. The temperature was measured daily. The day 30, 45, and 60, the samples were analysed P, Ca, Mg and K.

The moisture content was determined at 105°C for 24 h in a hot-air oven [9]. The pH was measured by using a direct reading type pH meter with glass electrode and a calomel reference electrode. To analyze the organic carbon and organic matter, the Walkley and Black method was used. Ca, Mg and K were analyzed by ICP-OES. The nitrogen (digested), TP (digested), and E. *coli* were determined in accordance with Standard Methods [10].

3. RESULTS AND DISCUSSIONS

3.1 Mixed waste characteristics

The optimum moisture content of mixed waste is important for the microbial decomposition of the organic waste. Thus, the rubber factory waste alone produces inadequate quality compost due to low moisture, high carbon contents and high C/N ratio. The addition of rubber factory waste with high nitrogen organic wastes in composting is one of the promising ways to reduce C/N ratio and raise the moisture content of the end product. The moisture content between 50-70% is the most suitable for composting and should be maintain during the active bacterial reaction periods such as mesophilic and thermophilic growth.

Mixed wastes are created in order to reach the optimal C/N ratio and aid in achieving adequate aeration. Cattle manure is a natural organic waste with rich nitrogen, and is commonly added to other wastes to increase nitrogen content and to enrich the compost with active biomass. The initial physicochemical characteristics of the mixed wastes obtained before the composting are shown in Table 3.

3.2 Characteristics of the co-composts by different mixed wastes

Fig. 2 shows that daily temperature of each reactor during the 60-day experimental period. Note that the daily ambient temperature is also included in the figure. The temperature change during the composting has a profound effect on the efficiency of the composting process. At the starting of the composting process (day 1-4), the mesophilic bacteria contributed to the temperature rise. As the temperature increased higher than 35°C, thermophilic bacteria took over as the leading group of bacteria causing the temperature to decrease. In the final stage of the composting, mesophilic bacteria became active again. Usually, the compost obtained under thermophilic temperature is stable and pathogens free [11].

Table 3. Initial characteristics of mixed wastes for composting

Parameter	Mixed wastes before Compost			
	Reactor 1	Reactor 2	Reactor 3	Reactor 4
Moisture (%)	66.3	65.8	58.8	42.1
pH	7.2	7.2	7.9	7.9
Organic carbon (g/kg)	69.2	77.0	109.4	92.0
Organic matter (g/kg)	119.3	132.7	240.0	210.3
Nitrogen (g/kg)	2.38	1.41	1.64	1.80
C/N Ratio	29.1	54.6	66.7	51.1
EC (mS/cm)	0.31	1.06	4.54	6.82
Nutrient elements (%)				
-Ca	2.51	0.71	0.49	1.48
-Mg	0.21	0.04	0.19	0.38
-K	0.16	0.12	0.87	1.32
-P	0.15	0.16	0.16	0.3
E.Coli (MPN/gm)	-	>1100	>1100	>1100

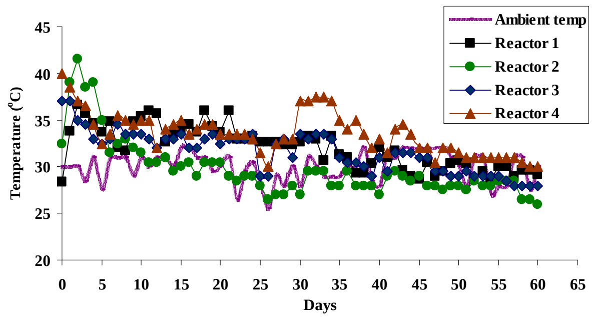

Fig.2. Variation of temperature in the mixed waste compost at various stages.

Fig 3 shows the moisture content in each reactor during the 60-day experimental period. Moisture content is an important factor to control because it influences the structural and thermal properties of the mixed wastes, as well as the rate of degradation and metabolic process of microorganisms. Composting was inhibited when the moisture content was less than 40%. On the other hand, the reactor 2 was turned into anaerobic condition at moisture content more than 70% due to the pH in the mixed wastes (rubber waste : water hyacinth : dewatered sludge from seafood industry) of the co-composting material (Fig. 3). The metabolic process of microbial is efficient when the moisture content was 40 – 60% [12]. The similar trends were observed in [13].

The pH is a parameter which greatly affects the composting process. The initial pH values of mixed wasted ranged from 7.2 to 7.9. The optimum pH values should be between 6 and 7.5 for bacterial []. During the starting period, the pH value rises to 8.3 in reactor 3 and 4. This result is due to the decomposition of proteins and the elimination of carbon dioxide. These high pH values are later reduced because the microorganisms produce acids during the decomposition process. Typically, the pH value will first drops steadily meaning the composting material hydrolyzed very rapidly. Then the pH value will rise which show that the rate of aerobic biodegradation is faster than that of hydrolysis. After that, the pH value will not change until the end of the composting period [14].

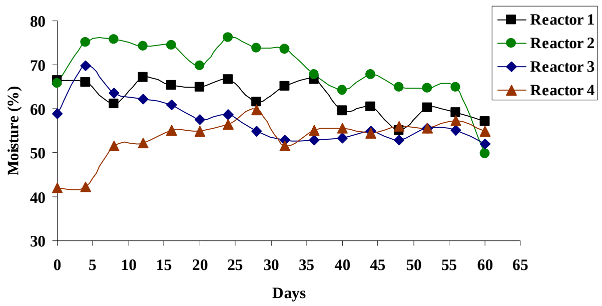

Fig.3. Variation of moisture content (%) in the mixed waste compost at various stages.

Fig. 4 shows the pH of each reactor during the 60-day experimental period. At the beginning of composting, the pH slightly increased in the reactor 1 and 2, and decreased in the reactor 3 and 4 (Fig. 4). Nitrification in the reactor 4 may contribute to the lower pH values. After that, the pH tends to rise towards neutral again when these acids have been converted to carbon dioxide by microbial activity. In the final stage of the composting, the pH remains unchanged.

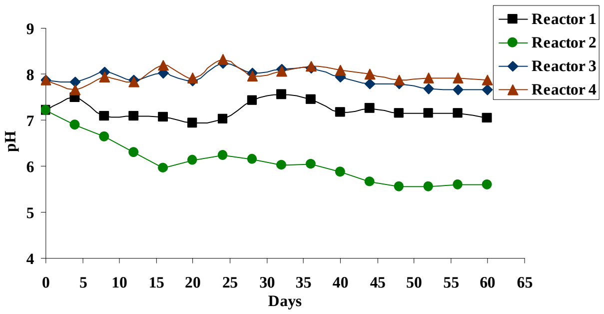

Fig.4. Variation of pH in the mixed waste compost at various stages.

Fig. 5 shows the level of organic carbon in the mixed waste in each reactor during the 60-day experimental period. Carbon provides the preliminary energy source for the microorganism growth. Especially, bacteria, actinomycetes, and fungi need both carbon and nitrogen to grow. During composting, the organic carbon is converted into carbon dioxide and it is mainly influenced by the temperature [3].

Fig. 6 shows the level of organic matter in the mixed waste in each reactor during the 60-day experimental period. During composting process, the organic matter is decomposed by microorganisms, producing carbon dioxide and water. The breakdown of organic matter is a dynamic process achieved by microorganisms, when each group of microorganisms reaching its peak population at the optimum condition for microorganism activity. The evolution of organic matter in reactor 1, 2 and 4 was similar, they began with a rise until the 20th day, then a decline during the 35th – 45th day and a recovery at the end.

Fig. 7 shows the level of nitrogen in each reactor during the 60-day experimental period. Nitrogen is an important nutrient for composting process since the quantity of nitrogen determines the microorganism population growth. During composting, microbial activities decompose organic matter and transform complex nitrogen compounds into mineral forms such as NH_3, NH_4, and NO_3. Therefore, amount of nitrogen increases at the end of process.

Many research suggested that the composting will success when the initial C/N ratio of mixed wastes are range between 20 and 40 [2,14,15]. Fig. 8 shows the C/N ratio in each reactor during the 60-day experimental period. The C/N ratio may increase during composting period for mixed materials with a lower initial C/N ratio such as reactor 2, 3 and 4. The initial increase in C/N ratio happens when an alkaline pH combined with high temperature leads to volatilization of ammonia [16]. Such phenomenon may also happen when materials to be composted contain relatively large amounts of stable carbon compounds and easily decomposable nitrogen compounds [17].

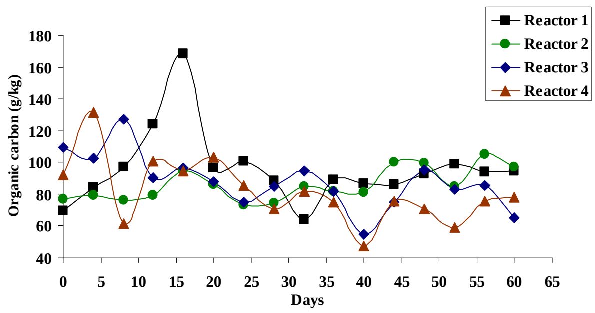

Fig.5. Variation of organic carbon in the mixed waste compost at various stages.

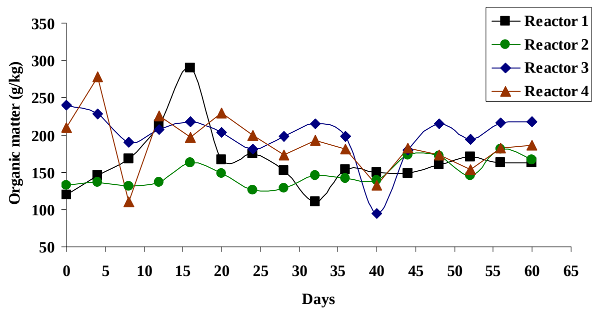

Fig.6. Variation of organic matter in the mixed waste compost at various stages.

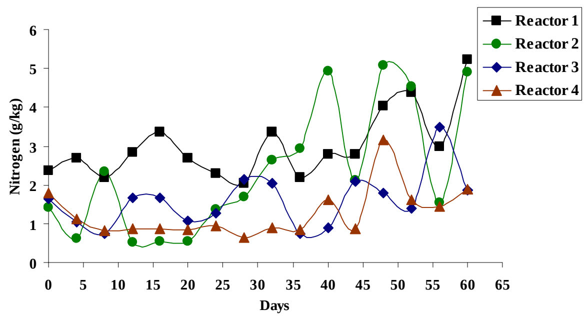

Fig.7. Variation of nitrogen in the mixed waste compost at various stages.

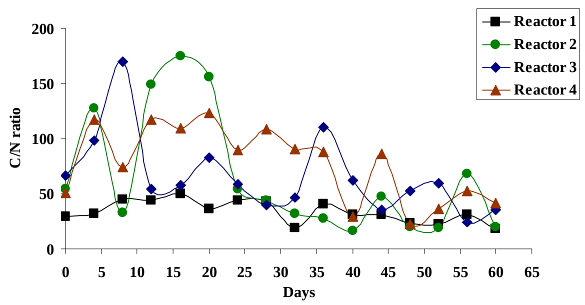

Fig.8. Variation of C/N ratio in the mixed waste compost at various stages.

3.3 Stability and maturity of compost

The most important factor affecting the successful application of compost for agricultural purpose is its degree of stability and maturity [18]. Compost stability is strongly related to the decomposition rate of the organic matter, as expressed by the biological activity. Normally, there are many criteria to judge the stability and maturity of a composting process. The composted material should contain a low organic content that will not undergo further fermentation when discharged on land and the pathogens should be inactivated. Haug [2] reported the approaches to measure the degree of maturity compost to be (1) temperature declines at the end of composting; (2) decreasing in organic content as analyzed by carbon content; and (3) the C/N ratio, absence of obnoxious odor and presence of white or gray color due to the growth of actinomycetes. However, the temperature was clearly diminished to ambient temperature to about 30°C after 35 days of composting and later remained stable that is indicated as a sign of composting stabilization [19]. Davidson et al. [20] report that composts with a C/N ratio of less than 20:1 are ideal for nursery plant production. Ratios above 30:1 may be toxic, causing plant death [21]. Le Minor [22] reported that E. *coli* is the most representative bacterium in the group of fecal coliforms.

Table 4 shows the characteristic of the final compost in each reactor. The composting in this study was marked by an important decrease in the number of E. *coli* (>1,100 to <3 MPN/gm). Note that the E. *coli* in Reactor 2 is still at 21 MPN/gm. During the composting, the moisture content in Reactor 2 is also higher than other reactors which may cause the delay in decreasing E. *coli* in this reactor. However, the E. *coli* of less than 1,000 MPN/gm can be used as a fertilizer [23].

Table 4. The characteristics of the final compost

Parameter	After Compost			
	Reactor 1	**Reactor 2**	**Reactor 3**	**Reactor 4**
Moisture (%)	57.2	49.7	52.1	54.9
pH	7.0	5.6	7.7	7.9
Organic carbon (g/kg)	94.5	97.0	65.4	78.3
Organic matter (g/kg)	162.9	167.2	217.3	186.8
Nitrogen (g/kg)	5.23	4.91	1.86	1.90
C/N Ratio	18.1	19.7	35.2	41.2
EC (mS/cm)	1.48	4.04	7.66	7.87
Nutrient elements(%)				
-Ca	2.04	2.65	1.66	3.06
-Mg	0.14	0.18	0.6	0.59
-K	0.56	0.66	1.97	1.62
-P	0.21	1.17	0.91	0.97
E.Coli (MPN/gm)	<3	21	<3	<3

Fig. 9 shows the C/N ratio during composting of each reactor. The final compost formed in all the reactors brown to brownish black color and soil-like texture after the maturation period. C/N – decomposition of organic matter is brought about by microorganisms that use the carbon as a source of energy and nitrogen for building cell structure. In the case of reactor 1 and 2, the C/N ratio indicated that it is optimum to be maturity in the composting process.

Fig. 10-13 show that the percent of phosphorus contents, potassium contents, calcium contents, and magnesium contents in each reactor, respectively. The increase in nutrients content (N, P, K and Ca) during the composting process may be caused by (i) the loss of organic fraction or volatile solids as carbon monoxide [24] and (ii) the respiration of microorganisms. From the results, the final co-composts had the N, P, K and Ca contents high enough to allow them to be denominated as a fertilizer as described in Table 5. Table 5 summarizes the level of many substances including organic matter carbon, nitrogen, phosphorus, potassium, and calcium in the typical final compost in the legal sense according to [25].

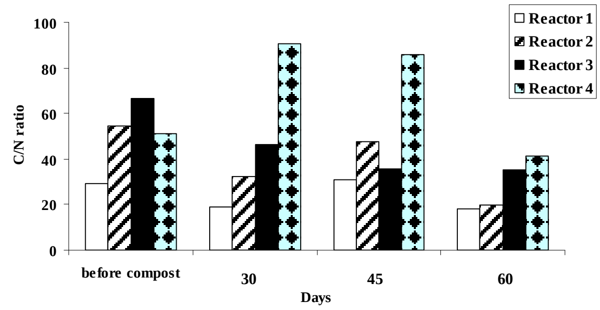

Fig.9. C/N ratio during composting

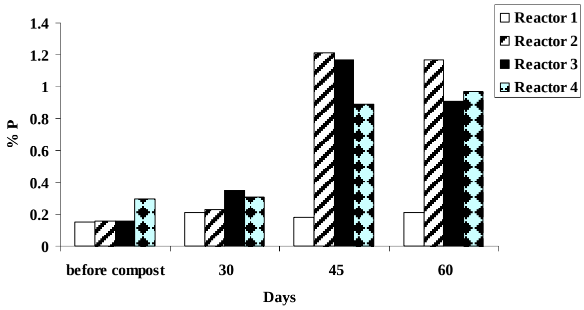

Fig.10. Phosphorus contents during composting

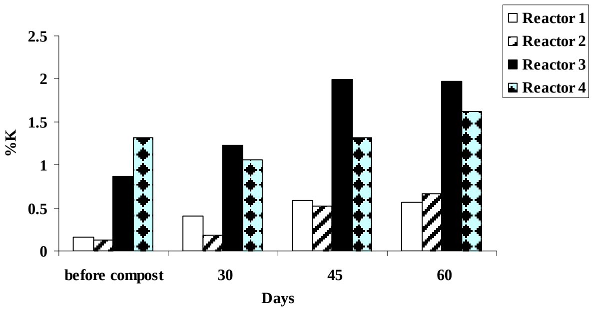

Fig.11. Potassium contents during composting

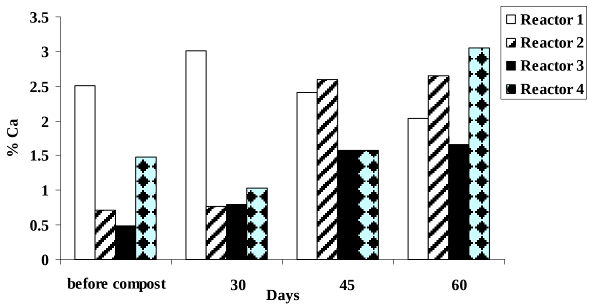

Fig.12. Calcium contents during composting

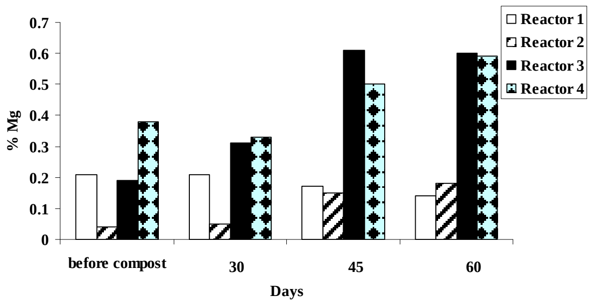

Fig.13. Magnesium contents during composting

Table 5. The typical characteristics of compost [24]

Substances	Typical compost (% by weight)
Organic matter	25-50
Carbon	8-50
Nitrogen (as N)	0.4-3.5
Phosphorus (as P_2O_5)	0.3-3.5
Potassium (as K_2O)	0.5-1.8
Calcium (as CaO)	1.5-7

4. CONCLUSIONS

It can be concluded that the rubber factory waste contained high C/N ratio and low moisture content. The co-composting of rubber factory waste, sewage sludges, cattle manure, and water hyacinth increased the moisture and improved to suitable C/N ratio in mixed waste. The optimal mixed waste materials in the composting of the rubber factory waste with high nitrogen-containing materials in this study is the rubber factory waste, sewage sludge and water hyacinth (in reactor 1 and 2). The final compost obtained from rubber factory waste, sewage sludge and water hyacinth can be promoted to fertilizer for agriculture. The N, P, K and Ca content of the final compost is high enough to allow it to be denominated as a fertilizer in the legal sense.

The results in this study are promissing because it indicates that composting can be an environmental-friendly sustainable alternative method to solve the disposal problems of two wastes (i.e., the rubber factory waste and sewage sludge).

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