CHAPTER 4 BIOLOGICAL TREATMENT

4.1 INTRODUCTION

Biological treatment is categorized into two major groups, which include the aerobic treatment and the anaerobic treatment. Both processes have a place in solid waste management as each process offers different advantages. In general, the operation of anaerobic process, which converts the organic materials to methane gas, is more complex than that of aerobic process. Aerobic treatment, on the other hand, requires oxygen for waste conversion, which not only offers the advantage of a relatively simple procedure, but also a significant reduction in waste volume.

Composting can be defined as the biological degradation of organic substances into a stable product, under controlled and aerobic environment (Epstein, 1997). Composting has become increasingly popular in the past decade as an alternative to incineration of decomposable organic wastes and can be considered as a useful treatment process for every kind of biodegradable wastes (US Congress, Office of Technology Assessment, 1989). Composting occurs within a physical matrix, where the effects are physical, chemical gradients, and site specificity of various factors that influence microbial activity (Miller, 1991).

The ability of composting to breakdown hazardous wastes has been carried out, which include materials such as crude oil, refinery sludge, and polychlorinated biphenyls (PCBs) (Hunter *et al.,* 1981). Composting converted the toxic compounds into non-toxic components through the rapid breakdown and oxidation process (Miller, 1991). Hogan *et al.* (1988) have shown the possibility of composting a variety of hazardous wastes from various industries including electronic industry with wastewater sludge as the additive.

Composting offers better results than other biological treatments for the treatment of hazardous wastes. This is due to the high activity of microbial combinations allowing the degradation of the biological component in the hazardous wastes (Miller, 1991). Composting of organic materials with chlorophenol-contaminated soil showed results indicating that frequent mixing and control of nutrient level can enhanced the degradation activity of the hazardous compound in the contaminated soil by indigenous microbes (Laine and Jorgensen, 1997). In this research an attempt was made to investigate the potentials and the most favourable composting conditions for the degradation of wastewater sludge and glycerol residue (a hazardous material) generated from the oleochemical industry.

4.2 COLLECTION OF SAMPLES

The wastewater sludge and glycerol residue were obtained from Cognis Oleochemical (M) Sdn. Bhd., (COM). Sludge was collected from the sludge holding tank of the wastewater treatment plant of the factory whereas glycerol residue was taken from the distillation plant in the palm·kernel oil transesterification process of Cognis Rika (M), (CRM). Raw sludge is black in colour and will eventually turn to reddish brown due to the presence of iron, as shown in Plate 1.

The glycerol residue is yellow in colour and available in powdery form as shown in Plate 2. The glycerol residue is odourless and high in alkalinity, which has a slight corrosive effect on the skin. Glycerol residue should be handled with appropriate skin protections.

4.3 PRELIMINARY ANALYSIS

4.3.1 Physical Analysis

Moisture Content

The moisture content of the samples was determined by weighing fresh samples before and after oven dried at 110°C for 24 hours (Csuros, 1997).

4.3.2 Chemical Analysis

(a) pH Determination

The solid samples were diluted in ultra pure water at 1:2.5 weight per volume ratios and pH was determined using pH meter (Hanna pHep).

Plate 1: Wastewater Sludge from Cognis Oleochemical (M) Sdn. Bhd.

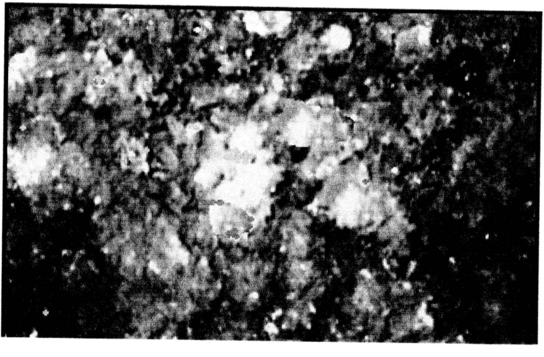


Plate 2: Glycerol Residue from Cognis Oleochemical (M) Sdn. Bhd.

(b) Total Carbon

Samples were digested at 400°C with sulphuric acid and were analysed with TOC analyser (Shimadzu TOC 5000A).

(c) Total Nitrogen

Samples were digested at 400°C with nitric acid and were analysed with the Kjeldahl analyser (model KJELTEC Auto 1030 Analyser).

(d) Nutrients Analysis

Samples were digested at 400°C with nitric acid and hydrogen peroxide and were analysed with the Inductively Coupled Plasma- Atomic Emission Spectroscopy (ICP-AES) model 2000 BAIRD, for the presence of potassium (K) and magnesium (Mg). The content of phosphorus (P) in the samples was detected using the vanadomolybdophosphoric acid colorimetric method with Shimadzu UV 1601 Visible Spectrophotometer.

4.3.3 Microbial Analysis

The analysis was carried out using nutrient agar (NA) and potato dextrose agar (PDA). The fresh material of sludge and glycerol residue were applied on NA and PDA and were incubated at 27°C for 48 hours.

4.4 COMPOSTING ANALYSIS

4.4.1 Preparation of Apparatus

The apparatus required in the experiment were weighing balance, square plastic containers, Hanna Instrument Membrane pH meter, ELGASTAT®UHQPD for pure water production and glassware. All plastic and glassware were thoroughly cleaned before utilization. Glassware and plastic bottles for metal analysis test were pre-soaked in detergent to eliminate organic matters, and then in diluted nitric acid to remove bound metals, and finally soaked in ultra pure water for 24 hours.

4.4.2 Composting Batch # 1 (Trial Composting)

The trial composting stages were set-up for eight different plots with various combinations with duplicates for each. The raw materials used were glycerol residue and wastewater sludge obtained from Cognis Oleochemicals (M), Teluk Panglima Garang; chicken manure was obtained from Institute of Biological Science Research Field, University of Malaya; garden waste consisting of clipped grass from University of Malaya football field, urea ($NH_2.CO.NH_2$ - AnalaR®) and soil. Since glycerol residue is considered hazardous and its disposal is costly, the first trial has more combination using glycerol residue. These materials were weighed to the appropriate mass ratio shown in Table 4.1, mixed and kept in plastic containers of 0.5 m long, 0.22 m wide and 0.15 m high.

Table 4.1: Composting Trial # 1 (Weight Combinations)

Combination	Ratios or %	Glycerol residue (GR)	Waste-water Sludge (WWS)	Urea (U)	Soil	Garden waste (GW)	Chicken manure (CM)
B1.1: GR	100%	15 kg	-	-	-	-	-
B1.2: WWS	100%	-	15 kg	-	-	-	-
B1.3: GR+CM	1:1	7.5 kg	-	-	-	-	7.5 kg
B1.4: GR+GW+ Soil	1:1:1	5 kg	-	-	5 kg	5 kg	-
B1.5: GR+ Soil	2:1	10 kg	-	-	5 kg	-	-
B1.6: GR+WWS+U	10:10:1	7.1 kg	7.1 kg	0.8 kg	-	-	-
B1.7: GR+WWS+Soil	10:10:1	7.1 kg	7.1 kg	-	0.8 kg	-	-
B1.8: WWS+CM	1:1	-	7.5 kg	-	-	-	7.5 kg

The compost materials were mixed daily until the moisture content reduced from 70% to nearly 60 % when the mixing process was carried out on alternate days and then to once a week when moisture content reduced to 40% - 45%.

The process of composting was monitored by recording the temperature of the composting material using mercury thermometer (0°C to 100°C). Physical (moisture) and chemical analysis (C, N, P, K and Mg) were also conducted for the initial day (Day 0), first day (Day 1), fifth week (Week 5) and final week (Week 9). Based on the results obtained in this trial, other combinations were worked out for the second composting trial.

4.4.3 Composting Batch # 2 (Second Trial of Composting)

Second composting trials were set up for 10 different plots with various combinations with duplicates for each. The raw materials used were glycerol residue and wastewater sludge from COM and CRM, Teluk Panglima Garang; goat manure from Institute of Biological Science Research Field, University of Malaya; garden waste consisting of clipped grass from University of Malaya football field, urea ($NH_2.CO.NH_2$ - AnalaR®) and mangrove soil from Kuala Selangor mangrove area. These materials were weighed to the appropriate mass according to the required ratios, mixed and kept in plastic containers (0.5 m in length X 0.22 m in width X 0.15 m high). Each set-up was labelled as indicated in Table 4.2.

Table 4.2: Composting Trial #2 Weight Combinations

ombination	Ratios or %	Glycerol residue (GR)	Waste-water Sludge (WWS)	Urea (U)	Man-grove Soil (MgS)	Garden waste (GW)	Goat manure (GM)
2.1- GR	100%	15 kg	-	-	-	-	-
2.2- GR: MgS: U	10:10:1	7.1 kg	-	0.8 kg	7.1 kg	-	-
2.3- GR: GW: MgS: U	1:4:1:1	2.1 kg	-	2.1 kg	2.1 kg	8.6 kg	-
2.4 -GR: WWS: MgS: GM	1:4:1:2	1.9 kg	7.5 kg	-	1.9 kg	-	3.6 kg
2.5 - WWS	100%	15 kg	-	-	-	-	-
2.6 - WWS: GM	1:1	7.5 kg	-	-	-	-	7.5 kg
2.7 - WWS: GM: GR	10:10:1	0.8 kg	7.1 kg	-	-	-	7.1 kg
2.8 - WWS: GM	1:2	-	5 kg	-	-	-	10 kg
2.9 -WWS: GM	3:2	-	9 kg	-	-	-	6 kg
2.10 - WWS: GM: GR	40:20:1	0.2 kg	9.8 kg	-	-	-	4.9 kg
2.11 - WWS: GM	2:1	-	10 kg	-	-	-	5 kg

The compost plots were mixed as in Trial # 1. Physical and chemical analysis were carried out similar to Trial # 1.

4.4.3 Composting Trial # 3

From the results of composting trial # 1 and # 2, third composting trials were set up on a larger scale for six different combinations with duplicates for each. The raw materials used were glycerol residue and wastewater sludge from COM and CRM, Teluk Panglima Garang; goat manure and soil from Institute of Biological Science Research Field, University of Malaya; fresh spent grain from Carlsberg (M) Sdn. Bhd., Shah Alam; and sewage sludge from tertiary treatment pond of Wastewater Treatment Plant, Indah Water Konsortium Sdn. Bhd., Cheras.

These materials were weighed to the appropriate mass according to the required ratios, mixed and kept in plastic containers of 0.75 m long, 0.50 m wide and 0.30 m high. Each set-up was labelled as indicated in Table 4.3:

Table 4.3: Lists of Composting Trial # 3 (Combinations with Appropriate Weight)

Combination	**Ratios or %**	**Glycerol residue (GR)**	**Waste-water Sludge (WWS)**	**Spent Grain (SG)**	**Sewage Sludge (SS)**	**Garden Soil (GS)**	**Goat manure (GM)**
1 - WWS	100%	-	50 kg	-	-	-	-
2 - WWS: GM	1:1	-	25 kg	-	-	-	25 kg
3 - WWS: SS	2:1	-	33 kg	-	17 kg	-	-
4 - WWS: SS: GS	2:1:1	-	25 kg	-	12.5 kg	12.5 kg	-
5 - WWS: SS: SG	2:1:1	-	25 kg	12.5 kg	12.5 kg	-	-
6 - WWS: SS: GR	5:3:1	6 kg	29 kg	-	15 kg	-	-

Composting mixture was mixed and temperature measurements were recorded as for the previous trials. The physical characteristics of the compost measured included the moisture content, volume reduction, final weight of compost, and the texture and colour of the compost. Chemical analysis carried out included pH, and mineral content i.e. N, P, K, Mg and the C/N ratio.

4.5 PLANTING TRIAL

Planting trial was set up to test the potential of the compost as organic fertilizer. Selected composts from the Third trial and second trial were tested at various combinations with different percentage of soil. The plant used in the trial was *Brassica* sp. (Chinese Mustard), which was planted in 0.10m X 0.10 m X 0.20 m, polybags. The compost used was on total-N basis, and 10 % of compost contributed 0.08- 0.1% of nitrogen while 50

% and 100% of compost contributed 0.4- 0.5% and 0.8-1.0 % of nitrogen, accordingly.

The trial was also conducted to test the potential of composts to act as planting medium.

Plot 1 (Combination # 1, compost from WWS):

1 A - 90 % garden soil + 10 % compost

1 B - 50 % garden soil + 50 % compost

1 C - 100 % compost

Plot 2 (Combination # 2, compost from WWS + goat manure):

2 A - 90 % garden soil + 10 % compost

2 B - 50 % garden soil + 50 % compost -

2 C - 100 % compost

Plot 3 (Combination # 3, compost from WWS + sewage sludge:

3 A - 90 % garden soil + 10 % compost

3 B - 50 % garden soil + 50 % compost

3 C - 100 % compost

Plot 4 (Combination # 4, compost from WWS + sewage sludge + soil):

4 A - 90 % garden soil + 10 % compost

4 B - 50 % garden soil + 50 % compost

4 C - 100 % compost

Plot 5 (Combination # 5, compost from WWS + sewage sludge + spent grain):

5 A - 90 % garden soil + 10% compost

5 B - 50 % garden soil + 50% compost

5 C - 100 % compost

Plot 6 (Combination # 6, compost from WWS: sewage sludge: glycerol residue, 40:20:1)

6 A - 90 % garden soil + 10% compost

6 B - 50 % garden soil + 50% compost

6 C - 100 % compost

Plot 7 (Inorganic Fertilizer)

Controls, C 1- 99% garden soil + 1 % inorganic fertilizer

C 2- 98% garden soil + 2 % inorganic fertilizer

Plot 8 (without Additive)

Control, C 3 - 100 % garden soil.

4.5.1 Planting Procedure

Seeds of Chinese mustard obtained from market were spread on normal garden soil and watered. The seeds were allowed to grow until 10 cm high with at least two mature leaves. The seedlings were transferred to the prepared polybags with the appropriate proportion of soil and compost. Three replicates with a single plant per replicate, were prepared. The planting process was carried out in an open space in ISB Farm, University of Malaya. The plants were watered twice daily. After two weeks of planting the plants were sprayed with insecticide (0.25% Malathion). The trial was allowed to proceed till 8 weeks where the plants were matured for harvesting and analysis.

4.5.2 Plant Analysis

After eight weeks of growth, the plants were harvested and analysed. The final number of leaves , final height of plants, and, fresh and dry weight of the plant, were recorded.

4.6 RESULTS

4.6.1 Analysis on Wastewater Sludge and Glycerol Residue

The results from the preliminary analysis conducted with wastewater sludge and glycerol residue samples are as shown in Table 4.4. The C/N ratio at 24 to 26 indicated that the wastewater sludge and glycerol residue could be used for biodegradation trials.

Table 4.4: Characteristics of Sludge and Glycerol Residue Obtained from The Preliminary Analysis.

Parameters	Wastewater Sludge	Glycerol Residue
Moisture Content (%)	86.82 ± 2.24	4.82 ± 0.09
pH Determination	7.43 ± 0.15	10.8 ± 0.20
Total Carbon (%)	93.78 ± 1.62	18.37± 1.20
Total Nitrogen (%)	3.92 ± 0.71	0.7 ± 0.5
C:N ratio	23.92	26.24
Phosphorus (%)	4.9 ± 2.51	1.44 ± 0.3
Potassium (%)	0.7 ± 0.6	7.68 ± 0.8
Magnesium (ppm)	76 ± 1.81	149 ± 3.6

The N/P/K ratio for wastewater sludge was 3.92: 4.9: 0.7 and hence the resulting composting from wastewater sludge would be beneficial to plant.

Microbial Analysis

The results from the microbial analysis of the wastewater sludge using nutrient agar (NA) and potato dextrose agar (PDA) are as indicated in Table 4.5. No growth was observed on both the NA and PDA when glycerol residue was introduced.

Table 4.5: Results of The Microbial Test for The Wastewater Sludge Using NA and PDA

Microbial Media	Observations of the media exposure to fresh material of sample
Nutrient Agar	After 72 hours of incubation at 27°C, six colonies of bacteria grew with different appearance, colour and texture. The colonies were labelled S1, S2, S3, S4, S5, and S6.
Potato Dextrose Agar	After 72 hours of incubation at 27°C, 2 colonies of fungi were detected with distinct colour and texture. The two colonies were labelled as F1 and F2

Due to the presence of six different colonies on the NA, the colonies were isolated to obtain pure colony and inoculated onto Eosin Methylene Blue (EMB) agar and Salmonella Shigella (SS) agar to observe the possibility of the colonies to grow on the two specified media. Results of the inoculation on EMB and SS agar are shown in Table 4.6.

Table 4.6: Results of Inoculation of The Six colonies on EMB and SS Agar.

Colonies	**EMB Agar**	**SS Agar**
S1	X	X
S2	Grew well on EMB but lack of the green sheen, thus concluded that S2 is not *Escherichia* sp.	Can grow on SS but indicated that S2 is neither *Salmonella* sp. nor *Shigella* sp.
S3	X	X
S4	Grew on EMB but limited only at the inoculation points without green sheen thus concluded that S4 is not *Escherichia* sp	X
S5	X	X
S6	Slow growth on the EMB agar with the lack of green sheen, thus concluded that S6 is not *Escherichia* sp.	X

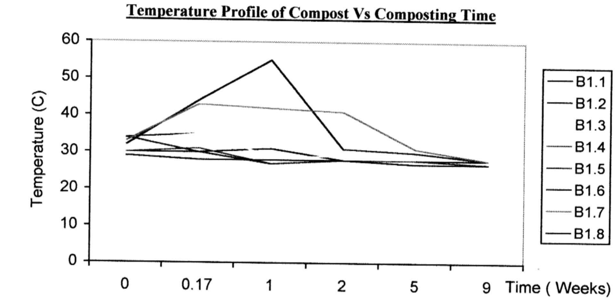
Note: X = No growth at all.

It can be concluded that there were at least six different indigenous bacteria and two different fungi in the company's wastewater sludge, but none in glycerol residue.

4.2.2 Composting Trials

4.2.2.1 Batch # 1 Composting (Preliminary Composting)

The temperature of the eight different compost plots set up with various combinations is shown in Figure 4.1.



Note : Combinations of the compost

B1.1: Glycerol residue (GR)
B1.2: GR+ chicken manure
B1.3: GR+ garden waste (GW) + Soil
B1.4: GR+ Soil
B1.5: GR + Wastewater Sludge (WWS) + Urea (U)
B1.6: WWS + chicken manure
B1.7: WWS
B1.8: GR + WWS + Soil

Figure 4.1: The Temperature Profile of Batch I Composting Trial with Time.

The first composting trial showed that composting with glycerol residue is not possible, but wastewater sludge could be used. The temperature profile from the Batch 1 composting trial showed that composting did not occur in almost all combinations (containing glycerol residue). except B1.6: a combination of wastewater sludge and chicken manure and B1.7: 100% wastewater sludge. The microbiological test carried out on the compost mixture gave negative results (shown in Table 4.7) indicating that the glycerol residue literally inhibited microbial growth.

Table 4.7: Microbiological Analysis of The Compost Samples for Batch 1 Composting Trial.

Combinations	**NA**	**PDA**
B1.1: Glycerol residue (GR)	X	X
B1.2: GR+ chicken manure	X	X
B1.3: GR+ garden waste (GW) + soil (SL)	X	X
B1.4: GR+ SL	X	X
B1.5: GR + Wastewater Sludge (WWS) + Urea (U)	X	X
B1.6: WWS + chicken manure	√	√
B1.7: WWS	√	√
B1.8: GR + WWS + SL	X	X

Note : X = no growth at all √ = growth of microbes of at least one colony

The microbiological results indicated that combinations with glycerol residue gave negative results. B1.1, which consisted of 100% glycerol residue, did not decompose at all, as was observed with no temperature change. B1.2, B1.3 and B1.4 showed a slight increase in temperature on Day 1 indicating the presence of microbes at the early stages of composting. The temperature drop throughout the composting period showed that the number of microbes decreased and finally died out. This probably was due to the high alkalinity of the glycerol residue. The appearance of the "compost" after nine weeks is summarised in Table 4.8.

Table 4.8: Physical Appearance of The Compost After Week 9.

Combinations	Appearance
B1.1: Glycerol residue (GR)	Initial state of powdery form turned into semi-liquid state, as shown in Plate 3
B1.2: GR+ chicken manure (CM)	Finally turned into a semi-liquid state with foul-smelling odour.
B1.3: GR+ Garden waste (GW)+ Soil (SL)	Did not compose and retained its initial state
B1.4: GR+ SL	Became densely packed and turned into semi-liquid state.
B1.5: GR + Wastewater sludge (WWS) + Urea	Turned into a semi-liquid state releasing sharp, disturbing odour.
B1.6: WWS + CM	Turned into soil-like texture with earthly odour (shown in Plate 4).
B1.7: WWS	Turned into soil-like texture with earthly odour.
B1.8: GR + WWS + SL	Became very densely packed with foul odour.

4.6.2.2 Batch # 2 Composting (Second Trial of Composting)

The second composting trial was carried out with glycerol residue using various other combinations, including mangrove soil. This was to see whether the high salinity microorganisms will have any effect. All combinations with glycerol residue did not show any temperature increase again. The temperature profile and the pH changes are shown in Figure 4.2.

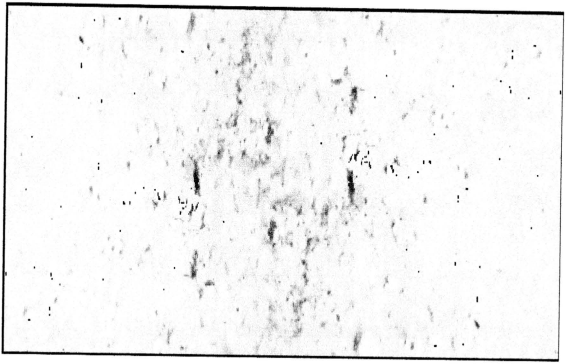


Plate 3: Glycerol Residue After Composting

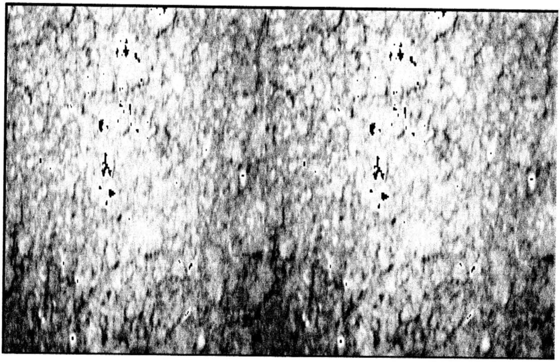
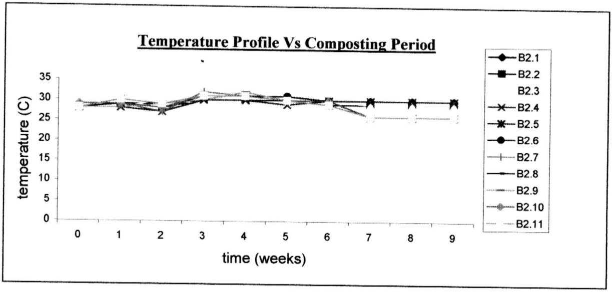
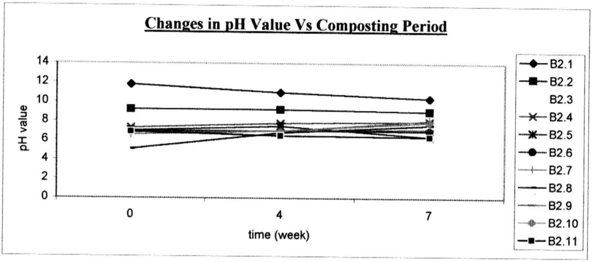


Plate 4: Combinations of Wastewater Sludge and Chicken Manure



(a)

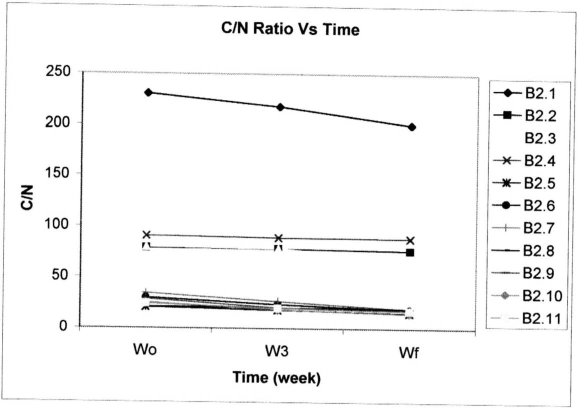


(b)

Note: Combination of compost	Ratio
B2.1- 100 % Glycerol Residue (GR)	100%
B2.2- GR: Mangrove soil : Urea	10:10:1
B2.3- GR: Garden Waste: Mangrove Soil: Urea	1:4:1:1
B2.4 -GR: Wastewater sludge (WWS): Mangrove Soil: Goat Manure (GM)	1:4:1:2
B2.5 - WWS	100%
B2.6 - WWS: GM	1:1
B2.7 - WWS: GM: GR	10:10:1
B2.8 - WWS: GM	1:2
B2.9 -WWS: GM	3:2
B2.10 - WWS: GM: GR	40:20:1
B2.11 - WWS: GM	2:1

Figure 4.2: (a) Temperature Profile of Compost with Time, (b) Changes in pH Value during Composting for Trial # 2.

The C/N ratio of the composts during the initial week, week 3 and the final week of the second composting trial, are as shown in Figure 4.3.



Note : <u>Combination of compost</u> — <u>Ratio</u>

Combination of compost	Ratio
B2.1- 100 % Glycerol Residue (GR)	100%
B2.2- GR: Mangrove soil: Urea	10:10:1
B2.3- GR: Garden Waste: Mangrove Soil: Urea	1:4:1:1
B2.4 -GR: Wastewater sludge (WWS): Mangrove Soil: Goat Manure (GM)	1:4:1:2
B2.5 - WWS	100%
B2.6 - WWS: GM	1:1
B2.7 - WWS: GM: GR	10:10:1
B2.8 - WWS: GM	1:2
B2.9 -WWS: GM	3:2
B2.10 - WWS: GM: GR	40:20:1
B2.11 - WWS: GM	2:1

Figure 4.3: C/N Ratio of Composts Throughout The Composting Process in Trial # 2

Materials which contained a high percentage of glycerol residue in the compost mixture, was not amenable by biodegradation. Combinations without the addition of a high percentage of glycerol residue decomposed to soil like particles as indicated in Table 4.9.

Table 4.9: The final appearance of the composts from Trial # 2

Combination	Physical Appearance at Week 9
B2.1- Glycerol Residue (GR)(100%)	Unchanged in terms of degradation and turned into semi-liquid state.
B2.2- GR: Mangrove soil (MgS): Urea (10:10:1)	Unchanged from the initial state except the top surface was covered with oil-like liquid (shown in Plate 5).
B2.3- GR: Garden Waste: MgS: Urea (1:4:1:1)	GW was unchanged in terms of degradation, released sharp ammonia odour.
B2.4- GR: Wastewater sludge (WWS): MgS: Goat manure (GM)(1:4:1:2)	Became more densely packed, released foul-smelling odour (Plate 6).
B2.5- WWS (100%)	Turned into finer soil-like particles.
B2.6- WWS: GM (1:1)	Turned into finer soil-like particles (shown in Plate 7).
B2.7- WWS: GM: GR (10:10:1)	Turned into finer soil-like particles (shown in Plate 8).
B2.8- WWS: GM (1:2)	Turned into finer soil-like particles.
B2.9-WWS: GM (3:2)	Turned into finer soil-like particles.
B2.10- WWS: GM: GR (40:20:1)	Turned into finer soil-like particles.
B2.11- WWS: GM (2:1)	Turned into finer soil-like particles.

The microbial analysis conducted showed that some microbes were present in a few compost combinations. The observations of the growth on NA and PDA are shown in Table 4.10.

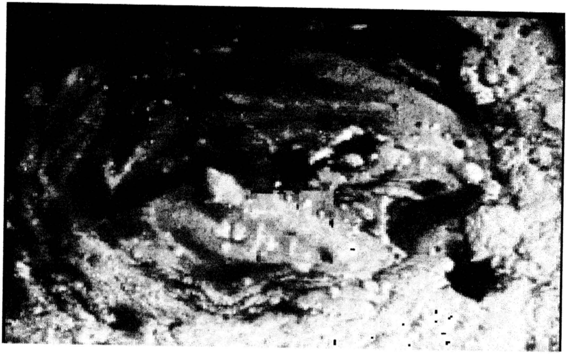


Plate 5: Combination of Glycerol Residue, Mangrove Soil and Urea

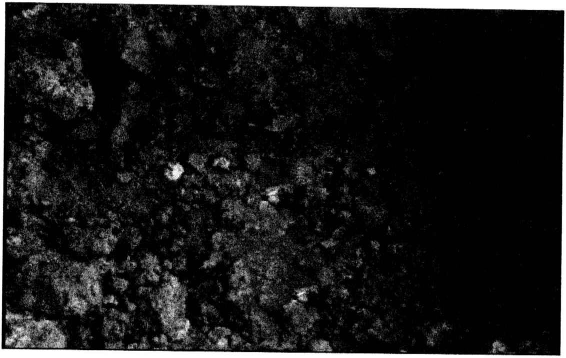


Plate 6: Combination of Glycerol Residue, Wastewater Sludge, Mangrove Soil and Goat Manure

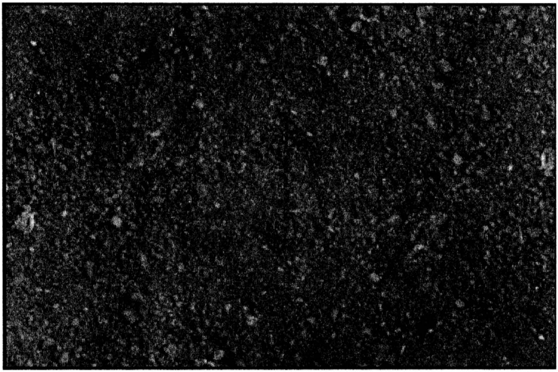


Plate 7: Compost with Combinations of Wastewater Sludge and Goat Manure (1:1)

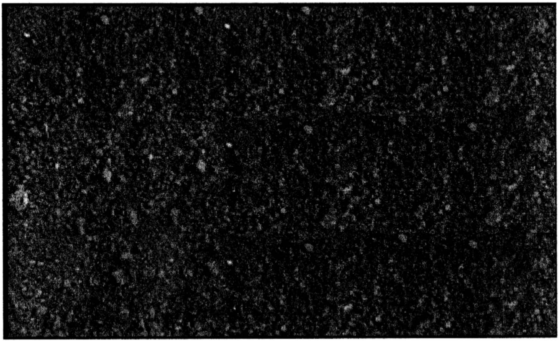


Plate 8: Compost from Wastewater Sludge, Goat Manure and Glycerol Residue (10:10:1)

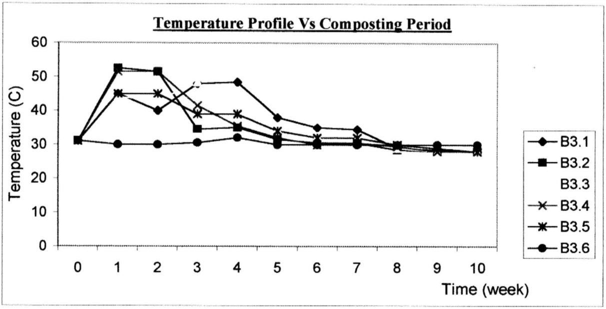
Table 4.10: Microbiological Analysis of The Compost Samples at Week 9 for The Second Composting Trial.

	Medium	
Combinations	**NA**	**PDA**
B2.1- Glycerol Residue (GR)	No growth at all	No growth at all
B2.2- GR: Mangrove soil (MgS): Urea	No growth at all	No growth at all
B2.3- GR: Garden Waste: MgS: Urea	At least three different colonies of bacteria, indicated that the medium inhibit rapid growth of the organisms particularly decomposing microbes.	No fungal growth
B2.4 - GR: Wastewater sludge (WWS): MgS: Goat manure (GM)	At least two different colonies of bacteria, indicated that the medium inhibit rapid growth of the organisms particularly decomposing microbes.	No fungal growth
B2.5- WWS	Growth of at least two different colonies.	Growth of white fungi
B2.6- WWS: GM	Growth of at least two different colonies.	Growth of white fungi
B2.7- WWS: GM: GR	Growth of at least two different colonies.	No fungal growth
B2.8- WWS: GM	Growth of at least one colony	Growth of white fungi
B2.9-WWS: GM	Growth of at least one colony	Growth of white fungi
B2.10- WWS: GM: GR	Growth of at least two different colonies.	No fungal growth
B2.11- WWS: GM	Growth of at least three colonies	Growth of white fungi

Results from the biological analysis indicated that microbes are present in the trial composts but the growth and activities of these microbes, particularly the decomposers, are inhibited in the mixture with glycerol residue. The glycerol residue inhibited composting.

4.2.2.3 Batch 3 Composting (Third Trial of Composting)

In the third composting trial, it was decided that wastewater sludge would be used as the main material and glycerol residue was used in only one treatment. A few combinations gave promising results. The data of temperature profiles of the composting process of the third trial for 10 weeks are shown in Figure 4.4.

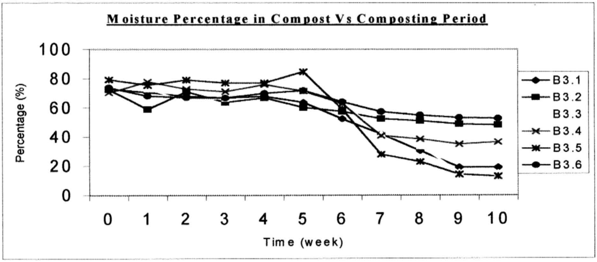


Note: B3.1 – Wastewater Sludge (WWS)
B3.2 - WWS: Goat Manure
B3.3 - WWS: Sewage Sludge (SS)
B3.4 - WWS: SS: Garden Soil
B3.5 -WW S: SS: Spent Grain
B3.6 - WWS: SS: GR

Figure 4.4: Temperature Profile of Compost during The Composting Process in Trial # 3.

When wastewater sludge was used alone (without glycerol residue), the final composting trial gave a much satisfactory result particularly from B3.2 (wastewater sludge and goat manure) and B3.4 (wastewater sludge, sewage sludge and garden soil). Data obtained indicated that composting was possible with addition of suitable additives such as soil and goat manure and sewage sludge, which contained indigenous microbes to allow the compost to undergo composting. B3.6, a combination of sewage sludge, wastewater sludge and a slightly high percentage of glycerol residue (11%) did not undergo composting process. It can be concluded that a high percentage of glycerol residue retarded composting, probably caused by its high alkalinity and high sodium salt content.

From the temperature data obtained, the composting process was slow. This was probably due to the high moisture content of wastewater sludge, which acted as the main material in the composting combinations. The moisture content patterns on the composting mixture are shown in Figure 4.5.



Note: B3.1 – Wastewater Sludge (WWS)
B3.2 - WWS: Goat Manure
B3.3 - WWS: Sewage Sludge (SS)
B3.4 - WWS: SS: Garden Soil
B3.5 -WW S: SS: Spent Grain
B3.6 - WWS: SS: GR

Figure 4.5: Moisture Content in The Compost Mixture, over Week 0 to 10.

The weight loss of the composts is shown in Figure 4.6.

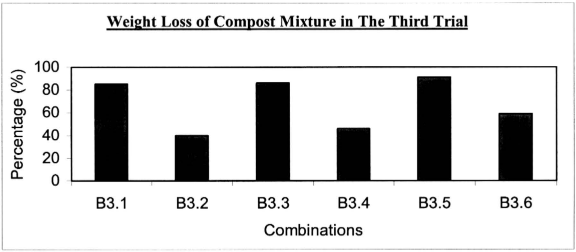


Figure 4.6: Weight Loss of The Composts at The Final Stage.

The nutrients nitrogen, phosphorus, potassium and magnesium, and C/N ratios are shown in Table 4.11, 4.12, 4.13, 4.14 and Figure 4.7, respectively.

Table 4.11: Percentage of Nitrogen in The Compost Mixture at 0,5 and 9 weeks.

Compost Combinations	**Week 0 (Initial)**	**Week 5**	**Week 9 (Final)**
B3.1 – Wastewater Sludge (WWS)	0.902 ± 0.06	0.774 ± 0.18	0.833 ± 0.09
B3.2 - WWS: Goat Manure	0.721 ± 0.23	0.545 ± 0.06	0.346 ± 0.07
B3.3 - WWS: Sewage Sludge (SS)	0.911 ± 0.05	0.830 ± 0.03	0.864 ± 0.17
B3.4 - WWS: SS: Garden Soil	0.622 ± 0.04	0.581 ± 0.05	0.601 ± 0.003
B3.5 -WWS: SS: Spent Grain	1.241 ± 0.07	1.063 ± 0.09	1.0115± 0.09
B3.6 - WWS: SS: GR	0.711 ± 0.05	0.638 ± 0.07	0.438 ± 0.11

Table 4.12: Percentage of Phosphorus in The Compost Mixture at 0,5 and 9 Weeks.

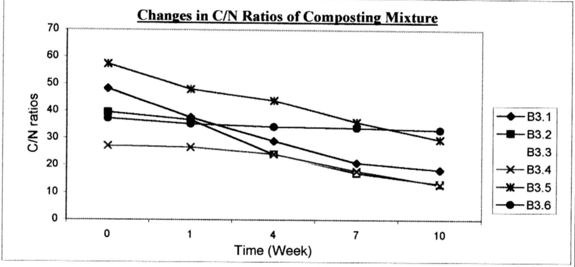
Compost Combinations	Week 0 (Initial)	Week 5	Week 9 (Final)
B3.1 – Wastewater Sludge (WWS)	7.84± 2.1	10.14± 1.9	13.32± 3.4
B3.2 - WWS: Goat Manure	6.53± 1.2	8.97± 1.8	9.52± 1.0
B3.3 - WWS: Sewage Sludge (SS)	7.58± 4.2	9.52± 4.5	14.60± 4.9
B3.4 - WWS: SS: Garden Soil	5.43± 2.8	8.55± 3.7	8.89± 4.9
B3.5 -WWS: SS: Spent Grain	4.73± 1.3	6.48± 2.5	10.33± 4.1
B3.6 - WWS: SS: GR	6.58± 2.7	8.17± 1.1	8.67± 2.1

Table 4.13: Percentage of K in Compost at Week 0,5 and 9.

Compost Combinations	Week 0 (Initial)	Week 5	Week 9 (final)
B3.1 – Wastewater Sludge (WWS)	1.3 ± 0.7	0.6 ± 0.4	0.4 ± 0.1
B3.2 - WWS: Goat Manure	2.0 ± 0.4	1.2 ± 0.7	0.9 ± 0.4
B3.3 - WWS: Sewage Sludge (SS)	1.8 ± 0.8	1.0 ± 0.4	0.7 ± 0.1
B3.4 - WWS: SS: Garden Soil	1.9 ± 0.3	0.8 ± 0.1	1.0 ± 0.2
B3.5 -WWS: SS: Spent Grain	1.8 ± 0.2	0.6 ± 0.1	0.5 ± 0.2
B3.6 - WWS: SS: GR	5.3 ± 1.5	5.1 ± 1.1	5.1 ± 0.8

Table 4.14: Mg Content (ppm) in Composting Mixture at Week 0, 5, and Week 9.

Compost Combinations	Week 0 (Initial)	Week 5	Week 9 (final)
B3.1 – Wastewater Sludge (WWS)	98 ± 22.9	104 ± 51.7	132 ± 64.8
B3.2 - WWS: Goat Manure	103 ± 34.8	129 ± 61.2	122 ± 33.6
B3.3 - WWS: Sewage Sludge (SS)	114 ± 44.9	135 ± 54.5	146 ± 14.8
B3.4 - WWS: SS: Garden Soil	99 ± 47.6	105 ± 71.6	118 ± 26.7
B3.5 -WWS: SS: Spent Grain	94 ± 67.4	97 ± 30.5	103 ± 11.9
B3.6 - WWS: SS: GR	159 ± 43.7	160 ± 56.4	159 ± 40.3



Note : B3.1 – Wastewater Sludge (WWS)
B3.2 - WWS: Goat Manure
B3.3 - WWS: Sewage Sludge (SS)
B3.4 - WWS: SS: Garden Soil
B3.5 -WW S: SS: Spent Grain
B3.6 - WWS: SS: GR

Figure 4.7: Changes in C/N Ratios of The Compost over 10 Weeks.

C/N ratios of the composts reduced throughout the composting period. Drastic reduction occurred at the initial stage of composting and the rate slowed when the compost reached the fourth week. The C/N ratios of treatment B3.1 (wastewater sludge), B3.2 (wastewater sludge with goat manure), B3.3 (wastewater sludge with sewage sludge), and B3.4 (wastewater sludge, sewage sludge and garden waste), reached the range of 12-20 at Week 9. The microbial analysis data are shown in Table 4.14.

Table 4.14: Results of Microbial Analysis After 48 Hours Incubation at 27°C.

Combinations	NA	PDA
B3.1	Growth of at least four different colonies labelled as the following: B3.1.1- creamy, flat & fimbriate colony, B3.1.2- creamy, umbonate & round colony, B3.1.3- white, domed & round, B3.1.4- creamy, umbonate & lobate colony.	Growth of white fungi
B3.2	Growth of at least six different colonies labelled as the following: B3.2.1- creamy, flat & fimbriate colony, B3.2.2- orange, convex and round colony, B3.2.3- creamy, flat & crenate colony, B3.2.4- white, raised & round colony, B3.2.5-creamy, umbonate & irregular colony B3.2.6 – yellow, umbonate & round colony.	Growth of at least one colony of white fungi and one colony of cream fungi
B3.3	Growth of at least five different colonies labelled as the following: B3.3.1- creamy, umbonate & round colony, B3.3.2- white, fimbriate & flat colony, B3.3.3- white, flat & irregular colony B3.3.4- white, raised & lobate colony B3.3.5- orange, domed & round colony.	Growth of at least one colony of white fungi
B3.4	Growth of at least five different colonies labelled as the following: B3.4.1- creamy, umbonate & round colony, B3.4.2- white, flat & fimbriate colony, B3.4.3- white, raised & irregular colony B3.4.4- pinkish, flat & round colony B3.4.5- orange, convex colony	Growth of at least one colony of white fungi
B3.5	Growth of at least three different colonies labelled as the following: B3.5.1- white, umbonate & irregular colony, B3.5.2- creamy flat & fimbriate colony, B3.5.3- white, & round raised colony	Growth of at least one colony white fungi
B3.6	No growth at all	No growth at all

Data obtained from the microbial analysis at the initial stage of batch 3 composting process indicated the presence of at least three different types of microbes in each compost combinations except in B3.6 (wastewater sludge, sewage sludge and glycerol residue), which gave negative results in NA and PDA. The composts, B3.1, B3.2, B3.3, B3.4 and B3.5 turned into soil-like particles as shown in Plate 9 and Plate 10.

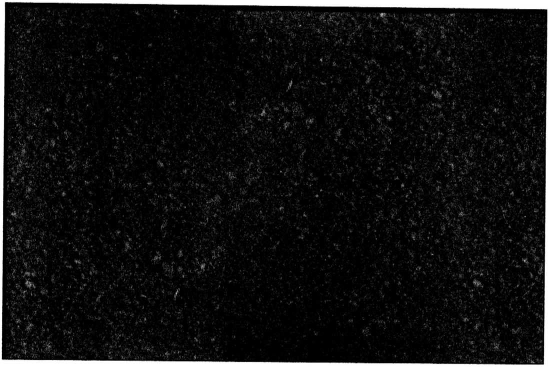


Plate 9: Compost Derived from The Mixture of Wastewater Sludge and Goat Manure in The Third Composting Trial.

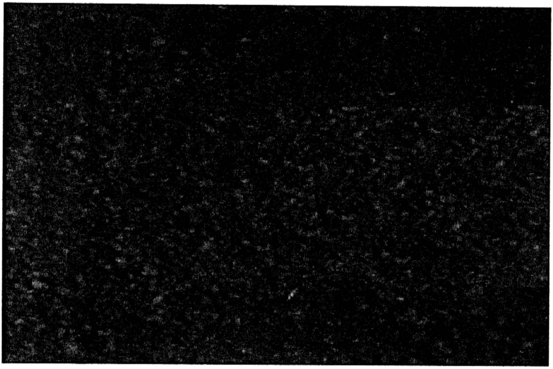


Plate 10: Compost Derived from Wastewater Sludge, Sewage Sludge and Soil from The Third Composting Trial.

4.2.3 Planting Trial

Planting trial conducted gave results on the suitability of applying the prepared composts to plants. The Chinese mustard seeds, which were labelled as 1B (50 % garden soil + 50% compost from WWS), 1C (100 % compost from WWS), 3 C (100 % compost from WWS + sewage sludge), 5 C (100 % compost from WWS + sewage sludge + spent grain), 6 C (100 % compost from WWS: sewage sludge: glycerol residue, 10:10:1), and 7 A (85% garden soil + 15 % inorganic fertilizer) died within a week of planting trial.

Results obtained from the planting analysis indicated that the moisture content of the plants when harvested were at a range of 62.7 % to 86.6 %. The average height of the plants when harvested varied with the treatment and type of compost being utilized. The percentage height increase are shown in Figure 4.8

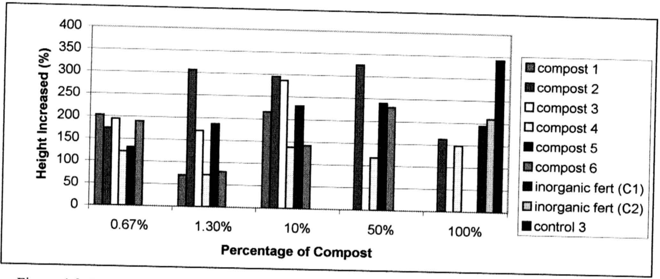


Figure 4.8: Increase in Height of The Plant Treated with Different Types and Percentage of Compost.

The average increment in weight of the plants and number of leaves differed with the type and the percentage of the compost being applied as shown in Figure 4.9 and Figure 4.10.

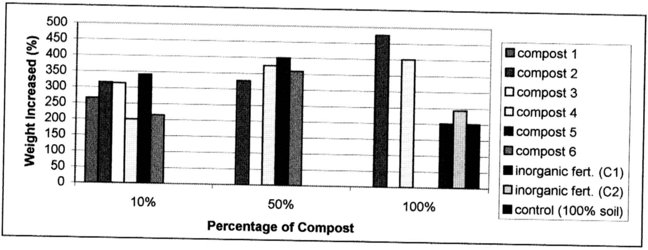


Figure 4.9: Weight Increase in Plant Treated with Different Types and Percentage of Compost

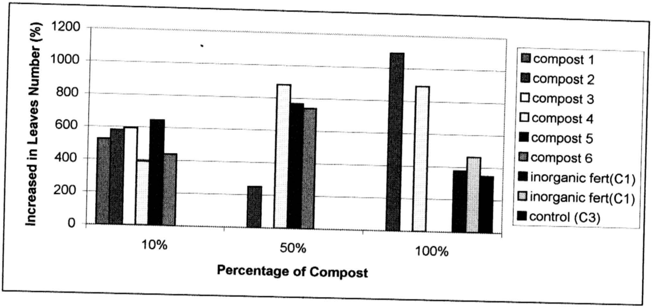


Figure 4.10: Increase in The Number of Leaves in Plants Treated with Different Types and Percentage of Compost.

Statistical analysis had been carried out to test the significance of the analysis conducted. Two-way analysis of variance (ANOVA) was conducted to test the significant difference of the data on various parameters between composts treated plants and the controls without additive and with inorganic fertilizer. The results indicated that compost 2 from wastewater sludge (WWS) and goat manure (GM), compost 4 from WWS, sewage sludge (SS) and garden soil, and compost 6 from WWS, GM and glycerol residue (10:10:1), yielded plants of higher weight increment, with f value of 2.8035 (P=0.05, df=2,2), 2.2175 (P=0.05, df=2,2) and 1.3325 (P=0.05, df=2,1), respectively. Meanwhile, higher height increments were indicated through the application of compost 4, compost 5 from WWS, SS and spent grain, and compost 6, with f-value of 10.2578 (P=0.05, df=2,2), 7.0821 (P=0.05, df=2,1) and 0.0964 (P=0.05, df=2,1) respectively. The increased in leaf numbers were significantly higher in plants with compost 2, compost 4, compost 5 and compost 6 with f-value of 1.0726 (P=0.05, df=2,2), 1.9699 (P=0.05, df=2,2), 1.8851 (P=0.05, df=2,1) and 2.0343 (P=0.05, df=2,1), respectively.

4.3 ECONOMIC ASPECT OF COMPOSTING

The objective of composting the wastewater sludge and glycerol residue from the industry was not only focused to conserve the environment from pollution, but also to minimise the waste management cost. The company had been spending RM 13 500 monthly, to treat and dispose the wastewater sludge generated. Table 4.16 indicates the approximate costs spent by Cognis Oleochemical (M) Sdn. Bhd. to dispose their wastes.

Table 4.16: The Costs Associated with The Waste Management by Cognis Oleochemical (M) Sdn. Bhd.

Type of Waste	**Cost of waste management (RM/ tonne)**	**Cost /year (RM)**
Wastewater Sludge	Cost = RM 150 / tonne	Total = RM 162 000
Glycerol Residue	Treatment = RM 645/tonne Transport =RM 48.24/tonne	Total = RM 242 735
	Total = RM 843.24/tonne	Total = RM 404 735

The process of composting also incurred some cost in the process of aeration, watering, mixing and others. The approximate cost for composting process is shown in Table 4.17.

Table 4.17: Approximate Costs of The Composting Process

Activities	Cost (RM/ tonne)
Transport	Varies ++
Labour (Mixing/ aeration)	RM 20.00
Watering	RM 6.00
Additives (e.g. soil, manure etc)	RM 200.00
Processing (Packaging, etc)	RM 100.00
Total	**RM 326.00 ++**

The current market price for one kilogram of organic fertilizer is RM 1.50 to RM 2.00 while inorganic fertilizer can be bought at RM 1.50 per kg, the compost produced from the wastewater sludge and glycerol residue could be marketed at RM 1.20/kg to RM 1.50 /kg. Due to volume reduction during the composting process, as much as 500 kg of compost will be produced from each tonne of sludge. Therefore, a tonne of wastewater sludge converted to compost could fetch RM 600 (RM 1.20 X 500), which gives a gross profit of RM 424.00 per tonne. The company would profit up to RM 457 920 annually. The composting cuts the cost of disposing the wastewater sludge and also increases the revenue to the company. Also, in appropriate ratio, glycerol residue can be utilized in the composting, which will reduce the amount of glycerol residue for disposal in Kualiti Alam.