공학석사학위논문

Selection of Suitable Additives for Composting Toilet

퇴비화 변소에 적합한 첨가물의 선택

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서울대학교 대학원

건설환경공학부

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이 논문을 공학석사학위논문으로 제출함

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Abstract

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This research presented the effects of mixing human feces with differing additives on improvement performance of composting, considering the efficiency of enhancement on decomposition of organic matter, reduction of nitrogen loss and pathogen bacteria removal. Three selected types of additives were available in Korea including sawdust, rice husk and rice husk charcoal used for mixing with human manure with ratio 1 : 2 (by human feces/additives, v/v). In addition, optimization of mixing ratio between human feces with rice husk charcoal for better improvement in composting performance was estimated also. Raw materials characteristics and changes

of compost properties during process were measured being moisture content, pH, organic matter content, total nitrogen content, NH_4 –N and Escherichia coli (E. coli) concentration. Decomposition rate of organic matter in the composting buckets of both feces – sawdust (F-S) and feces – rice husk (F-RH) were obtained at 13.4% and 18.6%, respectively while it was much higher in the composting bucket of feces – rice husk charcoal (F-RHC) being 32%. Total nitrogen content rose overtime of composting period in F-RHC bucket from 1.9% to 2.25%. However, in cases of F-S and F-RH, it reduced during first two weeks of process. In term of pathogen bacteria, E. coli concentration was rapidly reduced after first week of composting period in three cases. Interestingly, E. coli was not detected in F-RHC case after 5 weeks whilst F-RH and F-S cases were not completely inactivated E. coli after two months. These results therefore demonstrated the efficacy of using rice husk charcoal to enhance decomposition of organic matter, reduction of nitrogen loss and removal pathogen bacteria.

For optimization of composting, the mixing ratio of human feces with rice husk charcoal was also investigated. Mixtures with increasing amounts of rice husk charcoal at different ratio being 1:0.3; 1:0.5; 1:1; 1:2; 1:3 (by human feces / rice husk charcoal, v/v) were incubated in a laboratory scale reactor under aerobic conditions at 25°C for 30 days. The decomposition rate of organic matter evolution shows highest value at the mixing ratio of 1:1 being 33% and the lowest at mixing ratio of 1:3 (10.6%). The losses of total nitrogen mass was reduced when amount of rice husk charcoal

increasing. However, the total nitrogen mass loss rate was similar in three mixing ratio of 1:1, 1:2 and 1:3 being 15.9%, 15.5% and 15.2%, respectively. Therefore, moderate amounts of rice husk charcoal with mixing ratio of 1:1 would be the best compromise.

Keywords: Composting toilet; pathogen bacteria; organic matter decomposition; rice husk charcoal; nitrogen loss

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Chapter 1. INTRODUCTION

1.1. Background

The rapidly growing of population cause harmful effects on environment sanitation and human health. With an increasing population, there is a growing demand for food, land, space as well as efficient sanitation methods (Niwagaba et al. 2009, Hunter 2000, de Sherbinin et al. 2007). The importance of improved sanitation in safeguarding the health and wellbeing of human kind is well documented (Cairncross 2003, Moe 2006). Globally, at least 2.6 billion people lack access to basic sanitation (WHO 2006) and more than 90% of the sewage in developing countries is discharged untreated (Esrey 2001, Langergraber and Muellegger 2005). Improvement of sanitation systems for reduction of negative impact for environment become a big challenge recently. According to the Millennium Development Goals as many as 1.9 billion people will need to gain access to improved sanitation by 2015 in order to reach the proposed targets (WHO 2006).

The lack of access to improved sanitation potentially contributes to environmental pollution together with its consequences to society. In situations where sanitation is lacking, human excreta may become the main factor leading to environmental pollution and disease (Kulabako, Nalubega, and Thunvik 2007, Feachem 1983). There are some sanitation solutions to solve the problem about human excreta impact by improvement of conventional toilet.

In term of water based systems, the conventional flush toilet can be improved in few directions. In term of water source, they used some alternatives water source such as rainwater, grey water, or seawater for toilet flushing instead potable water (Devkota, Schlachter, and Apul 2015, March, Gual, and Orozco 2004, Gao, Li, and Jin 2008). According to the treatment methodologies can be achieved via various methods such as septic tanks, constructed wetlands (Zhang et al. 1996, Gao, Li, and Jin 2008). The other way to decrease the environmental pollution in residential areas, as well as in recipient surface waters and groundwater, and thereby decrease the negative impacts on society of untreated excreta, is to safely use the excreta nutrients in plant production (Vinnerås and Jönsson 2002). Source-separation toilet was designed to collect urine and feces of these fractions separately (Figure 1.1)(Rossi, Lienert, and Larsen 2009). The safe use of excreta nutrients as well as excreta treatment can be simplified by collecting in separation source (WHO 2006). Though all these sanitation technologies provide the same function of treating human excreta, sanitation toilet water based systems would still require the connection to the wastewater infrastructure. Then, energy is spent at the wastewater treatment plant to decompose the organic matter and separate the solids from the wastewater. Moreover, the pathway of waste water from household to the sewage treatment plant become the good opportunity of disease transmission (Feachem 1983)

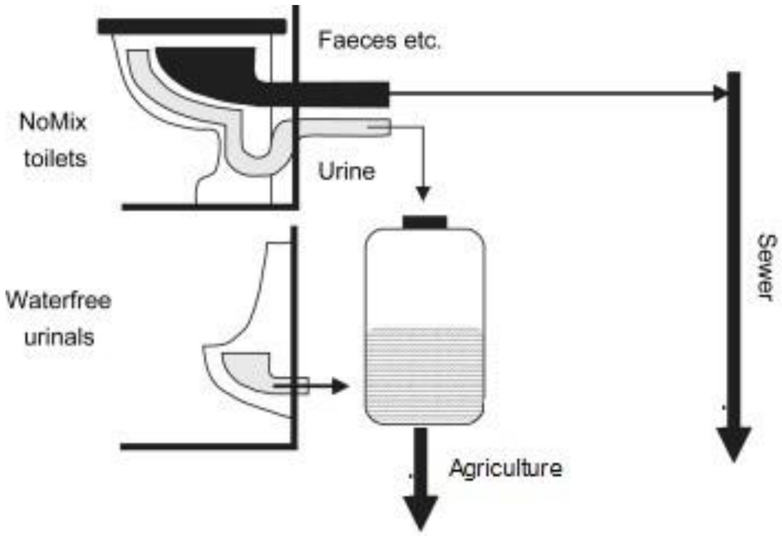

Figure 1.1: Diagram of source-separated toilet

According to composting based system, composting toilet was devised in two typical types (i.e. source separating composting toilet and mixed latrine microbial composting toilet) (Hill and Baldwin 2012) (Figure 1.2). Composting toilet has been used as a potential solution to the sanitation issues, which is able to decompose organic matter in human manure to become humus (Austin 2008, Sherpa 2009) as well as recycle of nutrient in human excreta and used as fertilizer (Morisaki et al. 1989). On the other hand, composting systems require little or no used of water for conveyance of wastes. The system therefore disconnect from both system water supply and wastewater infrastructure. Hence, composting toilet can be the solution for water scarce as well as reduction of water and wastewater infrastructure loading (Devkota et al. 2013). This can pathogen risks to user health when maintenance and performed of composting system. Therefore, addressing user involvement will be one of the key issues for the adaptation and sustainability of composting toilet systems in practical situations. Control of the pathogenic risk is an important issue to be considered in the use of resource recycling toilets and safety guidelines have been published (WHO 2006).

Bulking agents or additives are the essential material for composting toilet to make composting matrix as well as adjust the composting environment factors such as moisture, pH carbon to nitrogen ratio to increase the compost effective (Hijikata et al. 2015). In addition, the matrix plays a role of giving gas phase for aerial fecal decomposition with little odor. This thesis investigates the impact of rice husk charcoal additive on composting process and also comparison with sawdust and rice husk.

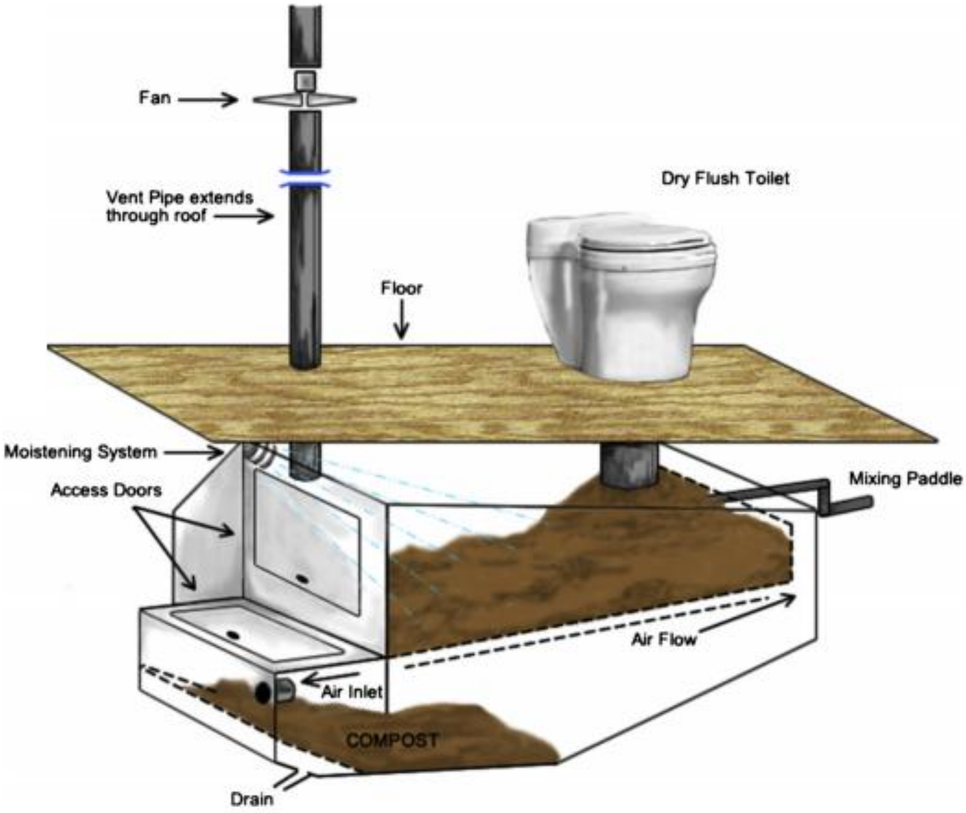

Figure 1.2: Composting toilet system “Source: (Anand and Apul 2014)”

1.2. Objectives

This study concentrates on the performance of composting process by mixing of human manure with difference types of additives (sawdust, rice husk and rice husk charcoal). The aim of this study therefore are to:

1) To compare the efficiencies of different additives used for composting toilet in terms of:

a) Enhance of decomposition organic matter

b) Reduction of nutrient loss

c) Removal of pathogen bacteria

2) To optimize the mixing ratio of human feces with rice husk charcoal for better performance of composting process.

a) Enhance of decomposition organic matter

b) Reduction of nutrient loss

3) To find the criteria of good composting for different additives application

1.3. Dissertation structure

The contents of this study is arranged in 5 chapters.

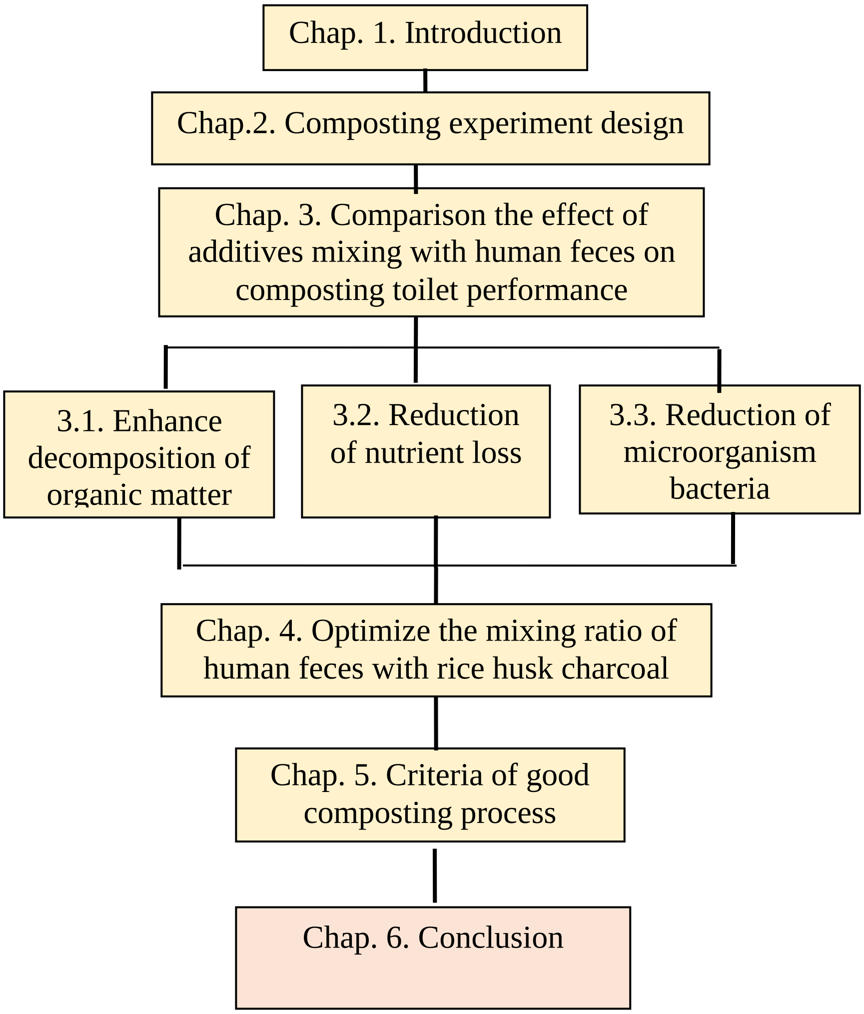

Figure 1.1. Dissertation structure

Chapter 1 includes some sections such as the general introduction, objectives and dissertation. Chapter 2 indicates the methods and design of composting process. Chapter 3 reports the efficiencies of three differing additives used for composting toilet in term of enhance decomposition organic matter, reduction of nutrient loss and removal of pathogen bacteria. Chapter 4 investigates the optimal mixing ratio of human feces with rice husk charcoal for better performance of composting process. Chapter 5 summaries the results from research and find the criteria of good composting for different additives application. And finally, chapter 6 is the conclusion of this study and recommendation for further study.

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Chapter 2: COMPOSTING EXPERIMENTS DESIGN AND RAW MASTERIAL CHARACTERISTICES

2.1. Introduction

Composting is the process to decompose of organic matter. Microorganisms oxidize organic compounds under aerobic conditions producing carbon dioxide, ammonia, volatile compounds, water and heat. Heat is released during the composting process some of which is used as energy for the operation of microorganism bacteria in term of reproduction and growth or destruction of pathogen bacteria. For microorganisms to survive and carryout the process of composting in the composting chamber, suitable environmental conditions need to be maintained.

There are few environment factors affecting the composting process including water content, temperature, carbon to nitrogen ratio, pH, particle size, porosity, oxygen concentration. These parameters depend on the formulation of the compost mix (Bernal 2009). Thus, additives were used as the important material to manage the operation of composting process.

Moisture in compost is the important and necessary factor for the performance of microorganism bacteria in the compost bucket, because it need aqueous medium to transfer of nutrients physically and chemically for accessible to microorganisms. However, too much moisture content in the compost bucket can be cased of anaerobic conditions. Composting systems can have drainage to remove leachate and reduce the moisture content of the compost. However, this method lead to the loss of nutrient in compost. Using of dry additives or turning of compost were the effective method to control of moisture content. From previous research, we got the boundary limits for moisture content for composting process. The moisture content should be higher than 40% because the dry conditions slow down the process of decomposition and require addition of water for microorganism bacteria activation (Liang, Das, and McClendon 2003), and moisture content should be lower than 65% (Zavala and Funamizu 2005).

In term of temperature, different phases of composting are indicated by differing range of temperatures. Composting start with mesophilic phase for few days at the range of temperature around ambient temperature. The temperature rapidly increase during the thermophilic phase and get the temperature above 45^{o}C under the activation of microorganism bacteria (Zavala 2006). Temperature is one of the key factors contributing to pathogen reduction in feces. Most enteric microorganisms die at a certain temperatures such as 45oC and all types of pathogens except bacterial spores are killed at temperature of about 55oC – 65oC (Hö glund 2001). Insulation is essential for maintaining temperature in the compost even when outside temperature is greater than 25 C (Niwagaba et al. 2009).

According to pH value, that affects the growth response of microorganism bacteria and pathogen bacteria also in a composting bucket. Different types of microorganism bacteria survive at different ranges of pH levels. More recently, (Bernal 2009) suggested a pH range of 6.7 – 9.0 being the optimization of the compost of animal manure. Maintaining pH in 6.7 – 9.0 range helps to control nitrogen losses by ammonia volatilization (Bernal 2009). The pH of the compost pile is observed to increase with increase in temperature (de Bertoldi, Vallini, and Pera 1983). According to removal of pathogen bacteria, pH of composting bucket should be greater than 9 (WHO 2006).

This chapter hence describes (1) the composting experiment design and (2) measurement methods of compost properties as well as evaluation the impact of difference additives (sawdust, rice husk and rice husk charcoal) on composting performance when mixing with human feces (including temperature, moisture content and pH)

2.2. Material and methods

2.2.1. Materials preparation

In this research, human manure (obtained from separated toilet "ECOSAN" in Seoul, Korea) were mixed with three types of additive as sawdust (collected from home carpentry industry), rice husk (collected from agriculture fields) and rice husk charcoal (dried rice husk was burned inside a close stainless steel fixed bed reactor of dimensions 0.5m x 0.2m x 0.15m for 2 hours to make rice husk charcoal) to simulate the composting process.

2.2.2. Composting experiment design

Composting process was monitored in two months with three matrixes (i.e. F-S, F-RH and F-RHC). The mixtures in an accordance with a ratio of feces and additives of 1:2 (by v/v) were added into a 5-liter-composting plastic buckets. The aeration condition was maintained during composting process by making the holes in surround and bottom of buckets with holes dimension and intensity being 3 mm and 2 holes per cm^2, respectively. The composts were not turned during two months monitoring. All samples were carried out in triplicate from the three composting buckets for analysis weekly, eight times of sampling was performed during composting process. Samples were taken from a half of the depth in composting buckets.

a b c

Figure 2.1: Composting bucket of F-RHC (a), F-S (b) and F-RH (c)

Table 2.1:

Summary of composting conditions for comparison of different additives (rice husk charcoal, rice husk and sawdust)

Items	Value
Additives	Rice husk charcoal, rice husk and sawdust
Monitoring duration	2 months
Turning	No turn
Buckets volume	5 L
Temperature	~25^{o}C
Sample taking	weekly

2.2.3. Measurement of materials chemical and physical properties

Observation of initial physical and chemical properties (i.e. temperature, moisture content, organic matter, pH, total nitrogen, NH_4 –N, total phosphorus and PO_4 –P) of raw material and its change in compost properties during composting process were tested. A thermal meter and a digital pH meter (*Mettler Toledo (R) SevenGo SG8 pH/Ion Meters*) were used to measure temperature and pH of the samples, respectively. To measure the pH, 10 gr of wet sample was taken and mixed with 10 ml of distilled water, thoroughly mixed by shaking well and allowed to stand for 30 minutes. In this study, moisture content was calculated based on fraction difference of wet weight and dry weight. Wet weight of samples was taken before drying the sample in an oven at 105°C within 12 hours till constancy of the weight. The dried samples were then cooled in a desiccator for dry weight Organic matter content was determined by heating dried samples in 2 hours at a temperature of 550°C, resulting in loss of weight, as a percentage of the dry soil. In order to determine total Nitrogen, we applied the Kjeldahl digestion method. NH_4 –N was determined by UV/Visible Spectrophotometer model HS-3300 after extraction with 2M KCl. The methodologies were followed (George Estefan 2013). Characteristics of feces and three additives were summarized in Table 2.2.

2.2.4. Measurement of microorganism bacteria

In this research, E. coli strain - a typical indicator of fecal pathogen and the norms of compost safety also reported with the number of colony forming units (CFU) was considered to estimate the microbial risk from various mixtures (F-RH, F-RHC and F-S). Quantification of E. coli was determined from membrane filtration standard method. In more details, the authors weighted a representative 25 g (wet weight) of the sample into a 250 mL container of peptone saline solution and centrifuged in 3 minutes for E. coli extraction. After adequate dilution (10 -10^5 times) with phosphate buffer, the extraction were inoculated in the m-Endo-Agar LES media. These inoculated media were incubated at 36 ±2°C within 21±3 hours, and followed by enumeration of colonies, which were then expressed as colony forming units per gram of compost (cfu/g).

Kinetics of microorganism inactivation in the three types of compost was calculated according to previous study, the die-off of bacteria was assumed to follow a first order decay equation (Jacobs 1960).

$$\ln\left(\frac{N}{N_0}\right) = -k.t \quad \text{(ep.1)}$$

Where, N_0 (cfu/g) and N (cfu/g) are the concentrations of microorganisms in compost at time 0 and t, respectively, k ($week^{-1}$) is the inactivation rate constant, and t (day) is the retention time.

Table 2.2:

Physicochemical and biological properties of raw material (average ± standard deviation, n = 3)

Items	Feces	Rice husk	Rice husk charcoal	Sawdust
Organic matter (%)	80 ± 2	90 ± 2.5	30 ± 2	85 ± 2
Moisture content (%)	80 ± 5	12 ± 1	3 ± 0	22 ± 2
pH	5.3 ± 0.3	6.8 ± 0.3	9.3 ± 0.1	6.3 ± 0.3
Total Nitrogen (%)	2.2±0.1	0.5±0.01	0.1	0.2±0
Total Phosphorus (%)	1±0.1	1.3±0.1	3.8±0.3	1.1±0
Log 10 (E. Coli concentration)	6 - 6.5	nd	nd	nd

2.3. Result and discussion

2.3.1. Temperature

During composting process, a range of temperature in three composting buckets varied between 25^{o}C and 42^{o}C (showed in Figure 2.2) in perspective of ambient temperature of 25^{o}C. Overview, temperature inside composting buckets was depended upon the presence of additives. It is resulted in a rapidly increase of temperature and reached to thermophilic phase after first 7 days of the process. However, the decrease order of temperature maintenance remaining in compost buckets was F-RHC > F-S > F-RH. These results are attributed to relatively of the size of size of additives to the heat loss. Due to the size of (rice husk > sawdust > rice husk charcoal), hence temperature of F-RH and F-S buckets remained shorter than it in F-RHC bucket (Figure 2.2). On the other hand, in the compost buckets of F-S and F-RH, higher temperature was reached than it in a compost bucket of F-RHC. This was due to the higher available carbon source or organic matter at the initial material of composting (as seen in Table 2.1), which provided a better condition for the growth and biological activity of microorganisms (Vinnerås, Björklund, and Jönsson 2003).

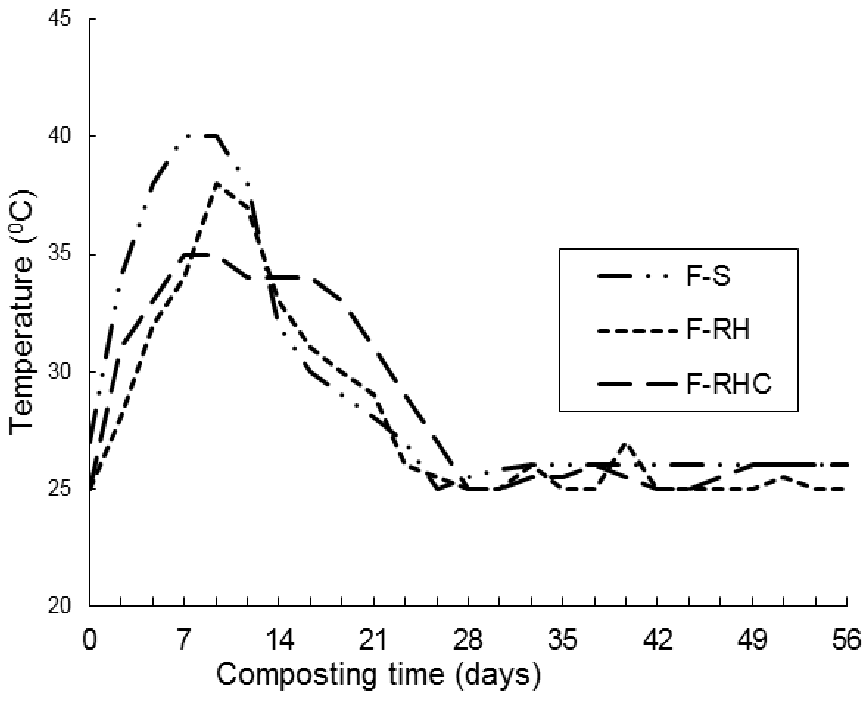

Figure 2.2: Changing of temperature during decomposition of F-S, F-RH and F-RHC

2.3.2. pH and moisture

2.3.2.1. pH

The results in Figure 2.3 showed that the change of pH's tendency was seemly similar in all of mixing additives. The pH was much increased during first two weeks of composting process then gradually decreased. The pH value of F-RH and F-S buckets were similar during the composting period and that was significantly lower than the pH value in F-RHC bucket. Otherwise, pH tend to increase significantly during first two weeks from 8.9 to 9.5 for F-RHC bucket, from 6.4 to 7.3 for F-RH bucket and from 6.3 to 7.5 for F-S bucket, then it gradually decreased to 9.2, 6.5 and 6.8 on the last day of process for F-RHC, F-RH and F-S, respectively (Figure 2.3). It is explained that the ammonium produced in the ammonification and mineralization of organic nitrogen process as a result under the activities of bacteria, and it was also reported in a previous work (Bishop and Godfrey, 1983). The decrease in pH at the later stage of composting was due to the formation of organic and inorganic acids by the decomposition of organic matter ((Morisaki et al. 1989). The higher of pH value in F-RHC bucket throughout the composting comparing with other ones due to the greater neutral pH of raw material (rice husk charcoal) which was provided in Table 2.1.

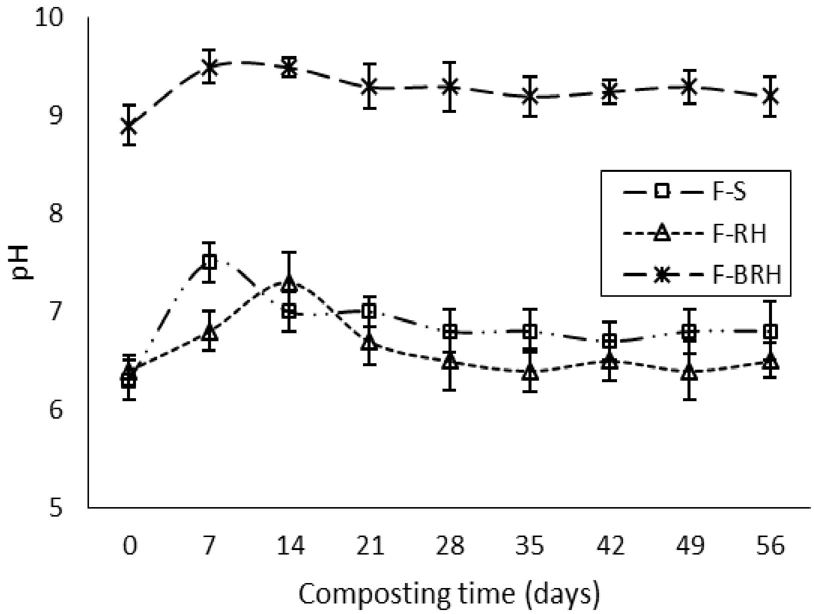

Figure 2.3: Changing of pH during decomposition of F-S, F-RH and F-RHC

2.3.2.2. Moisture

As seen in Figure 2.4, the moisture content varied differently in three composting buckets (both value and tendency). In the F-S bucket, the moisture content was slightly decreased in the first week of process from 68% to 66%, and finally stayed at 63% at the end of process. In contrast, in the F-RH bucket, the moisture content raised from 60% to 62% within a week and gradually reduced to 53% at the last day of composting process (Figure 2.4). The observation of moisture content in the F-RHC underwent a little variation during the composting period (moisture content around 51%). Because of the evaporation in perspective of high water content and the increase of temperature inside bucket, moisture content in F-S composting was dropped. Also, the increase in moisture content highlighted in the F-RH bucket could be attributed to the decomposition of the organic matter content of the rice husk resulting in moisture release into the faecal matter (Zavala and Funamizu 2005).

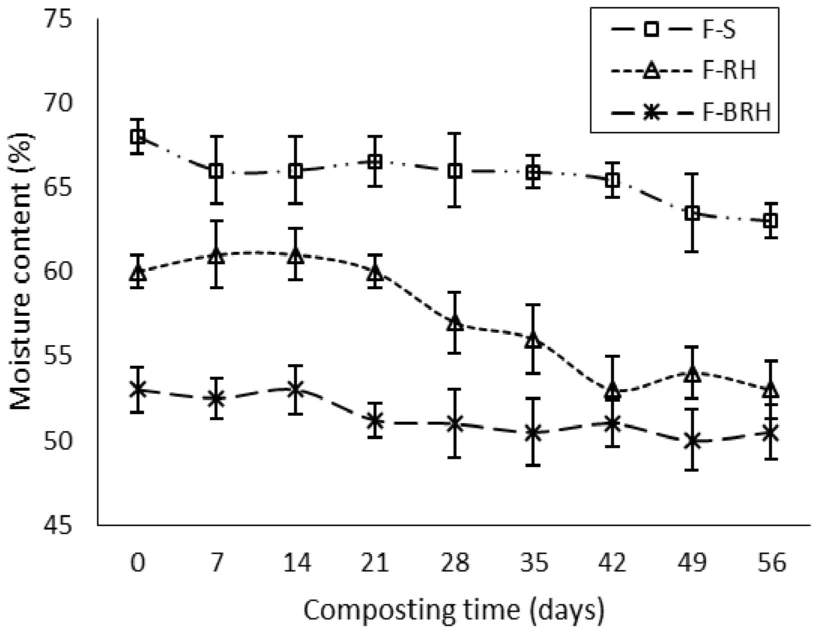

Figure 2.4: Changing of moisture content during decomposition of F-S, F-RH and F-RHC

2.4. Summary

This chapter compared the impact of three type of additives (i.e. rice husk charcoal, rice husk and sawdust) on environment factors during composting process. At the ambient temperature of 25^{o}C, mixing ratio between human manure with additives of 1:2 (by v/v) and no turning during process. The results could be reported that the raw materials play in important role of management of environment factors in composting bucket such as moisture content, pH and temperature. Higher temperature was shown in F-S and F-RH buckets than F-RHC bucket. In term of pH level, rice husk charcoal had high potential to improve pH value in composting bucket. In addition, this chapter also indicated some information about the range of environment factors which promote the operation of composting process.

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Chapter 3: COMPOARISON THE EFFECT OF ADDITIVES MIXING WITH HUMAN FECES ON COMPOSTING TOILET PERFORMANCE

3.1. Introduction

In the composting toilet, bulking agents has been frequently used as composting matrix, because the matrix plays a role of giving gas phase for aerial fecal decomposition with little odors. Moreover, one of the materials such as lime, soil, ash, sawdust, etc. is sprinkled to the human manure to keep away flies also to affect conditions (moisture, pH, temperature, nutrients, etc.), which impact on the rate of inactivation of pathogens in human manure (Austin 2008). Ultimately, the fertilizer obtained from the sanitized human manure composting from the toilet systems should be free of pathogens (WHO 2006). The latter is a major health concern considering that at household level, the product requires some handling (Sherpa 2009). On the other hand, nutrient loss is an unavoidable problem during the composting of organic waste. This is especially the case for nitrogen, the most essential fertilizer nutrient for crop production in many situations (Cooperband 1996). From previous research, the initial nitrogen of the manure was lost from 20% – 77% with 47–77% of nitrogen loss has been reported as resulting from ammonia volatilization during composting (Martins 1992). Additives were used to be the most efficient method to reduce nitrogen loss during composting, for example, alum, peat, and zeolite additives have been used to reduce ammonia volatilization during composting (Bernal 1993). In particular, this research arm to investigate the efficiency of additives (sawdust, rice husk and rice husk charcoal) mixing with human manure on enhancement of decomposition organic matter, reduction of nitrogen loss and pathogen bacteria removal.

3.2. Results and discussion

3.2.1. Decomposition of organic matter

The estimation of decomposition during composting was based on several indicators such as oxygen uptake rate, carbon dioxide (CO2) emission rate, mass balance or organic matter reduction rate (Ekinci, Keener, and Elwell 2002). In this research, organic matter content reduction was used as indicators to estimate the decomposition extent during composting period in three buckets. In Figure 3.1, the mineralization of organic matter's tendency was similar regardless of different additives. However, the amount of organic matter content in F-S and F-RH buckets in this study were significantly larger than F-RHC buckets because of higher initial organic matter available in sawdust and rice husk compared with rice husk charcoal (Table 1). Although the higher amount of organic matter in F-S and F-RH buckets seems to aid better mineralization than F-RHC but in fact, it was showed in reverse order as F-RHC > F-RH > F-S (i.e. from 53% ~ 36% for

R-RHC, from 86% ~ 70% for F-RH, and from 82% ~ 71% for F-S bucket).

As can be shown in Figure 3.2, decomposition rate of organic matter in three composting buckets were significantly high in first two week of composting period compared with other time. During two months of composting, decomposition rate of F-RHC bucket was much higher than F-S and F-RH buckets (i.e. 32% for F-RHC bucket, 18.6% for F-RH bucket and 13.4% for F-S bucket).

The reason for this phenomenon can be the high initial moisture content of F-S bucket (68%), because water displacing much of the air in the pore spaces in the compost bucket lead to reduction of decomposition organic matter, especially in case of no turning composting buckets, optimum moisture content for decomposition organic matter should range from 50% - 60% (Zavala and Funamizu 2005). In addition, Another important explanation might be from previous research about the properties of additives being the different level of lignin content, that is significant high in raw material like sawdust and rice husk (Lynch 1993). However, The bio-char product from the pyrolysis of raw materials is influenced by the pyrolysis temperature, its lignin, cellulose, and hemicellulose content and to a lesser extent the extractive concentrations of the raw materials (Antal and Grønli 2003). Lignin is the most recalcitrant component of the plant cell wall, the higher the proportion of lignin the lower the bioavailability of the substrate. The effect of lignin on the bioavailability of other cell wall components is thought to be largely a physical restriction, with lignin molecules reducing the surface area available to enzymatic penetration and activity (Haug 1993). In addition, high content of lignin might reduce the population of heterotroph micro-organisms on the sawdust surface and reduce their activity (Hijikata et al. 2015).

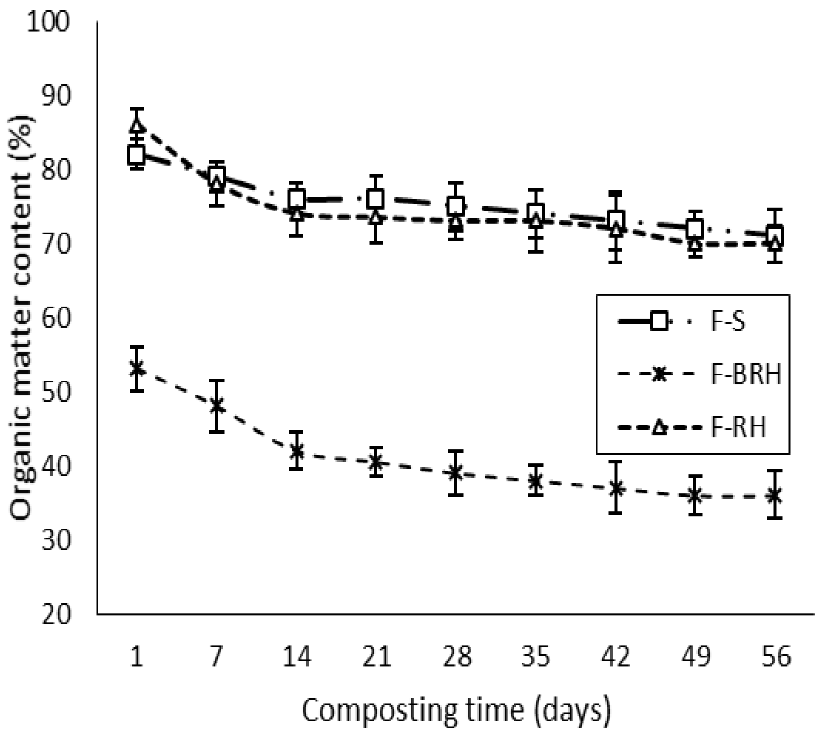

Figure 3.1: Changing of organic matter during decomposition of F-S, F-RH and F-RHC

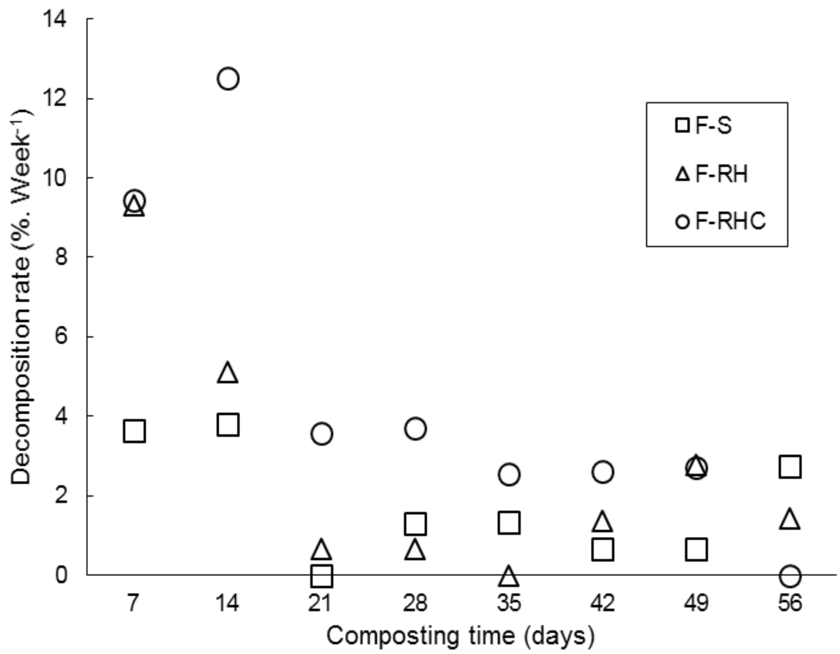

Figure 3.2: Changing of organic matter decomposition rate during decomposition of F-S, F-RH and F-RHC

3.2.2. Nutrient loss reduction efficiency

3.2.2.1. Nitrogen

In Figure 3.3, tendency of total nitrogen changing during composting period was varied in three composting buckets. Total nitrogen content in the F-S and F-RH buckets was decreased during first two week of the process (from 2% to 1.88% and from 2.1% to 1.86% ,respectively) and it was gradually increased to 2% and 1.9% afterward, whilst total nitrogen content rose overtime of composting in F-RHC bucket from 1.9% to 2.25%. The reason for rising of total nitrogen content in F-RHC bucket and F-S, F-RH buckets after thermophilic phase were the loss of dry mass by the emission of carbon dioxide as well as water evaporation by heat under organic matter mineralization of microorganism bacteria (Inoko et al. 1979).

The total nitrogen loss was calculated based on the dry mass balance after composting decreased with an increasing amount of rice husk charcoal additives. Amount of total nitrogen loss was highest in composting bucket of F-RH being 9.8 g, whilst total nitrogen loss in the composting bucket of F-RHC was 4.79 g. The different of total nitrogen loss rate in the composting bucket of F-RHC was totally difference comparing with other compositing buckets. The value shown in Table 3.1 were 16.5% for F-RHC bucket 36.9% for F-RH bucket and 34.15% for F-S bucket.

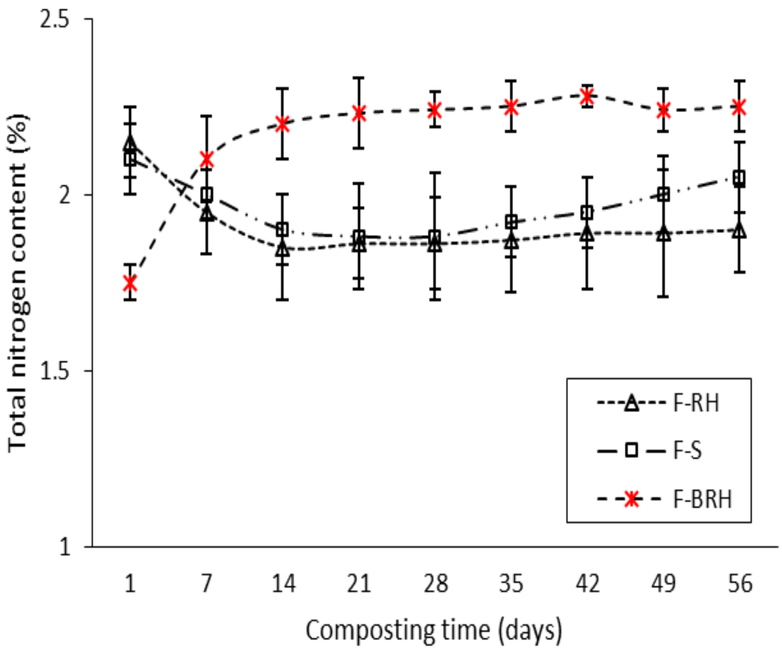

Figure 3.3: Changing of total nitrogen content during decomposition of F-S, F-RH and F-RHC

Considering the changes in concentrations of NH_4 –N, the typical trends for these two forms of nitrogen during aerobic composting were illustrated in Figure 3.4. During the first week, NH_4 –N concentration of three composting buckets increased significantly and reaching peak values of were 1010.3 mg.kg-1 for F-RH bucket, 875 mg.kg-1 for F-RHC bucket and 910 mg.kg-1 for F-S bucket. Based on the results from previous research (Mahimairaja et al. 1994) the ammonification occurred to an increase in temperature and pH, as well as the mineralization of organic-N compound and after an initial increase, NH4 –N concentration dropped in F-RH and F-S buckets by volatilization loss. However, amount of NH4 –N seemly stabilized during the process. The final NH4 –N concentration were found as 920 mg.kg-1 for F-RH bucket and 830 mg.kg-1 for F-S bucket and 854 mg.kg-1 for F-RHC bucket. The results thus demonstrated that rice husk charcoal has potential to absorb NH4 –N that leads to reduce the nitrogen loss via NH4 –N volatilization. The mechanism of NH4 –N absorption by rice husk charcoal can be explained, by the functions of carboxylic groups which may deprotonate and therefore form complexes with NH4+, and phenolic constituents could react with NH4+ to form stable complexes (Fernando, Xia, and Rice 2005). Some authors had also reported the nitrogen retention properties of other bio-charcoals. For example, black charcoal in soil could efficiently adsorb ammonia and act as a buffer for ammonia in soil (Oya and Iu 2002) and bamboo charcoal has effective on nitrogen conservation during the course of sewage sludge composting process (Hua et al. 2009).

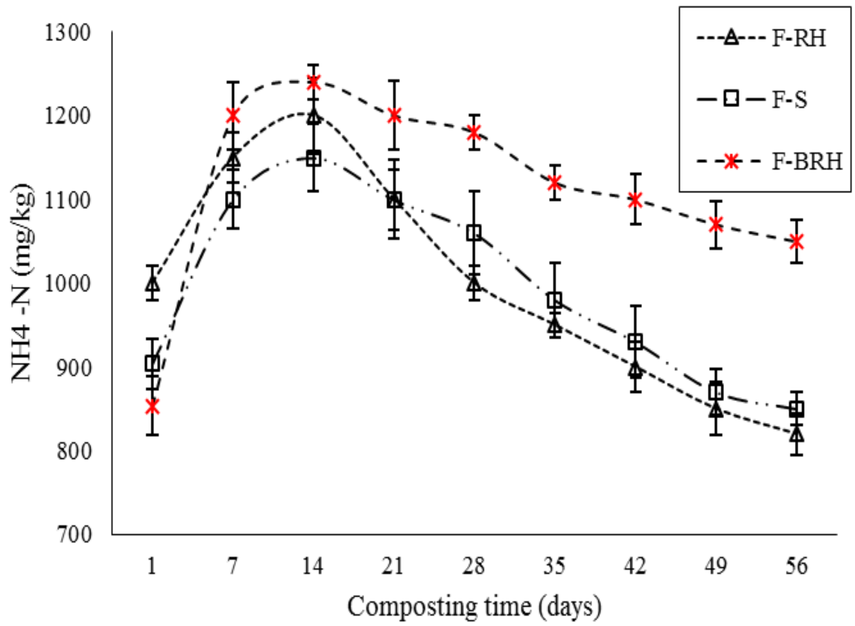

Figure 3.4: Changing of NH_4 –N during decomposition of F-S, F-RH and F-RHC

Table 3.1:

Mass balances and nitrogen loss during composting period of human feces and difference additives

Composting bucket	Initial compost				Final compost				Total nitrogen mass loss (g)	Nitrogen loss rate (%)
	Wet mass (kg)	Dry mass (kg)	Total nitrogen content (%)	Total nitrogen mass (g)	Wet mass (kg)	dry mass (kg)	Total nitrogen content (%)	Total nitrogen mass (g)		
F-RHC	3.52	1.66	1.75	29	2.1	1.08	2.25	24.2	4.8	16.5
F-RH	3.1	1.24	2.15	26.66	2.4	0.9	1.9	16.8	9.86	36.9
F-S	3.3	1.05	2.1	22.2	1.9	0.7	2.1	14.6	7.6	34.15

3.2.2.2. Phosphorus

The change of total phosphorus in three composting buckets followed the same trend as total nitrogen with a gradually increase throughout the composting process from 1% to 1.6% for F-S bucket, from 1.5% to 2% for F-RH bucket and from 3.3% to 3.4% for F-RHC bucket, this phenomenon can be explained by the net loss of dry mass (Figure 3.5) . Total phosphorus content of F-RHC bucket was higher than that of F-S and F-RH buckets because of the comparatively higher amount phosphorus in raw material. PO_4 –P of three composting buckets dropped significantly in the first two week from 620 $mg.kg^{-1}$ to 520 $mg.kg^{-1}$ for F-RH bucket and from 600 $mg.kg^{-1}$ to 490 $mg.kg^{-1}$ for F-S bucket, especially in F-RHC bucket decreasing from 750 $mg.kg^{-1}$ to 500 $mg.kg^{-1}$. It gradually decreased to 400 $mg.kg^{-1}$, 410 $mg.kg^{-1}$ and 450 $mg.kg^{-1}$ in F-RH, F-S and F-RHC buckets respectively (Figure 3.6). The loss of PO^4 –P is likely due to the mineralization of organic phosphorus and the consumption by microorganisms.

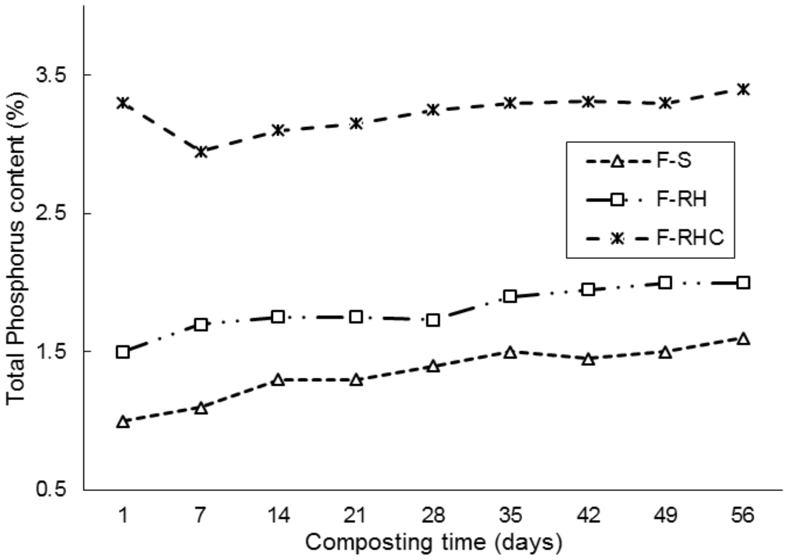

Figure 3.5: Changing of total phosphorus during decomposition of F-S, F-RH and F-RHC

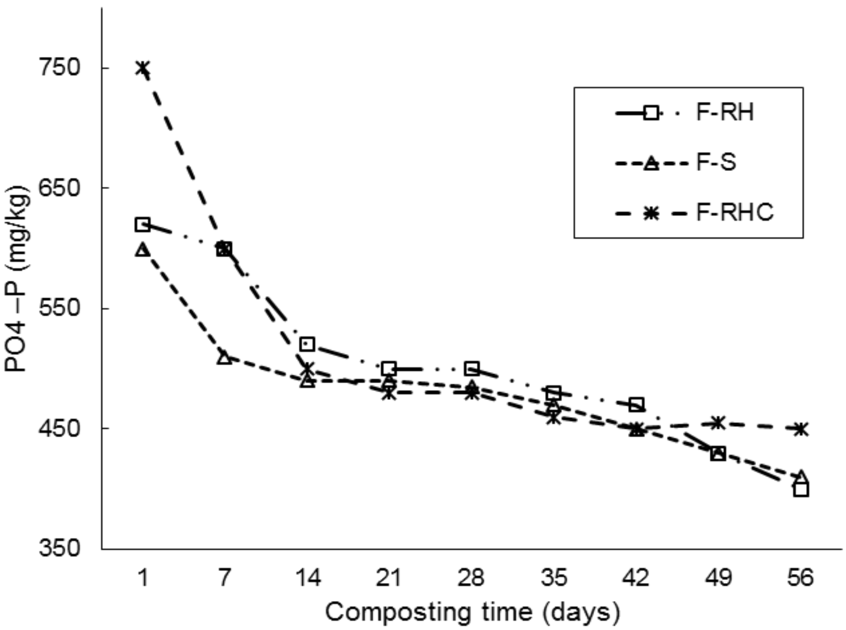

Figure 3.6: Changing of PO_4 –P during decomposition of F-S, F-RH and F-RHC

3.2.3. E. coli strain removal efficiency

The concentration of E. coli strain changing during composting period in three composting buckets were showed in Figure 3.7. As seen, the effectiveness of rice husk charcoal on removal of E. coli strain in human manure was higher than rice husk and sawdust, expressing in a reduction from 1.25×10^6 to 2.25×10^3 for sawdust and 3.2×10^6 to 3.2×10^3 for rice husk after two months composting whereas in case of F-RHC, E. coli strain was not detected after 5 weeks with an initial E. coli concentration of 8×10^5 (Figure 3.7).

In composting process, the purposes of additives (rice husk, rice husk charcoal and sawdust) presence are to control pH value and the moisture in composting bucket perspective, the major factors governing effect on reduction of pathogen bacteria in manure, addressed to temperature, moisture and pH were apparently not in the optimal range and no single factor was found to have significantly contributed to the reduction of the indicators (Sherpa 2009). Temperature is one of the key factors contributing to pathogen reduction in manure. Most enteric microorganisms die at a certain temperatures such as 45^{o}C and all types of pathogens except bacterial spores are killed at temperature of about 55^{o}C – 65^{o}C (Hö glund 2001). However, the temperature in three types of bucket (F-RH, F-RHC and F-S) did not reach the critical value during composting period (i.e.

temperature ranged from 25^oC to 40^oC) (Figure 2.2), hence its effects on the E. coli strain removal could not be easily quantified for three buckets. Similarly, low moisture content or desiccation (moisture content less than 20%) leads to microbial die off, since the microbes are unable to drive their metabolic processes in such an environment (Redlinger et al. 2001). However, the slightly reduction of moisture content in any of the buckets was resulted and indicated in Figure 2.4. The other discussion here is that the composting buckets is painted dark colour to absorb more heat from sunshine aiming temperature increasing and moisture reduction also. Colour of additives can also be attributed to improve composting process by absorption of heat such as efficiency of rice husk charcoal higher than sawdust or rice husk, but the investigated bucket did not include this case. In term of pH, the alkaline environment has an effectiveness on pathogen die-off, pH value of 9 and above could be optimal condition to removal of pathogen bacteria (WHO 2006). However, in the buckets with sawdust and rice husk additives, the pH value was less than 8 and only average pH in F-RHC bucket was greater than 9 (Figure 2.3). That could lead to the difference of E. coli reduction in three composting buckets of F-RHC, F-S and F-RH.

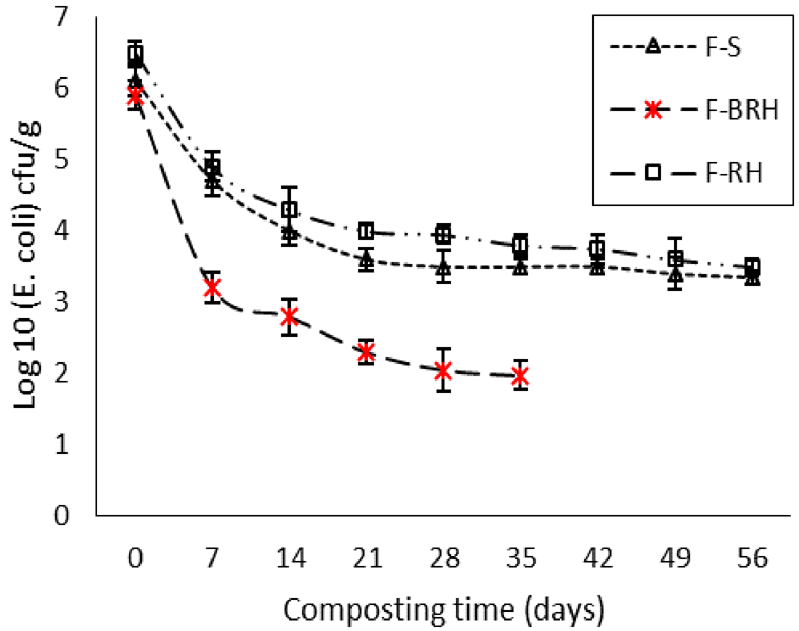

Figure 3.7: Changing of E. coli concentration during decomposition of F-S, F-RH and F-RHC

From Figure 3.8, the inactivation rate constant (*k*) of E. coli strain devised in three main periods of composting process. In three composting buckets, inactivation rate was totally different in the first week in comparison with other periods, this *k* was much higher than it in next two weeks. The E. coli concentration seemly unchanged after 3 weeks except for F-RHC bucket (E. coli was not detected after 5 weeks). In parallel, the result from F-RHC bucket showed the highest *k* – value in the first week in all three buckets with values of 6.2 week^{-1} for F-RHC bucket, 3.7 week^{-1} for F-RH bucket and 3.2 week^{-1} for F-S bucket. In addition, inactivation rate constant (k) was similar in three matrixes during other periods with the range of k – value from 1.0 week^{-1} to 1.2 week^{-1} for during next two weeks and from 0.12 week^{-1} to 0.23 week^{-1} for period after 3 weeks (see in Figure 5b). High pH (>9) in F-RHC bucket can be the explanation for better reduction of E. coli concentration in the bucket when compares to F-S and F-RH buckets. The changing dramatically of inactivation rate (k) after first week can be explained rapid die-off while microorganisms still adapt, and the faecal clods still break down, and thus more of the organisms come into contact with additives, and then a slower decrease when they have adopted after most faecal clods have disintegrated (Niwagaba et al. 2009).

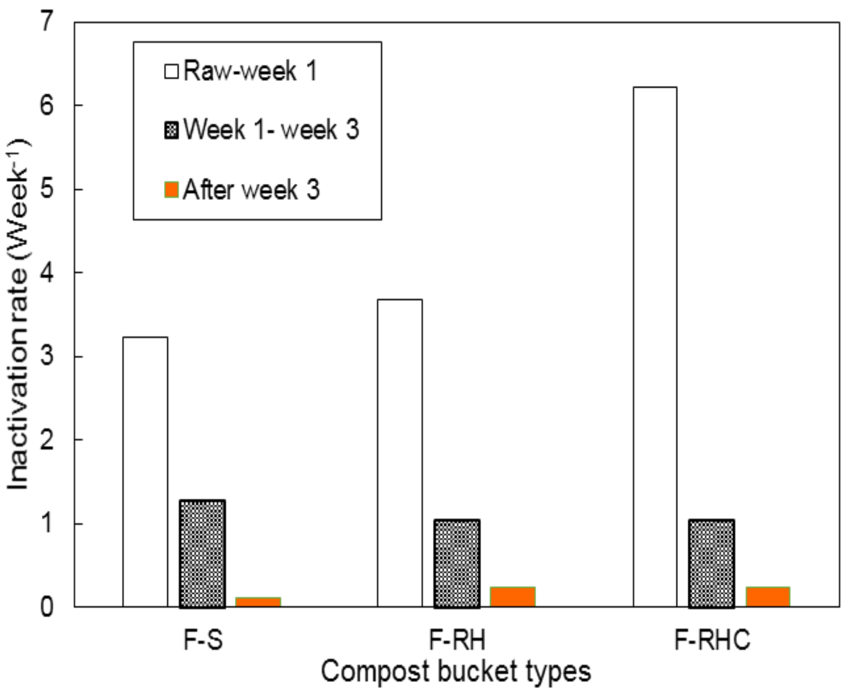

Figure 3.8: Changing E. coli inactivation rate during decomposition of F-S, F-RH and F-RHC

3.3. Summary

The results from this chapter demonstrated the superior efficiency of rice husk charcoal on decomposition of organic matter, reduction of nitrogen loss as well as pathogen bacteria removal compared with other additives. Rice husk charcoal contributed to improve decomposition of fecal matter by extent reduction of organic matter content after composting period with 32% of decomposition rate of organic matter. Rice husk charcoal was able for retention of nitrogen in the composting bucket. In term of microorganism bacteria, rice husk charcoal can realize the comprehensive outstanding with other additives, E. coli strain was not detected in F-RHC bucket after five weeks composting while E. coli still existing in F-S and F-RH after two months, high pH value available in rice husk charcoal is the main reason for die-off of E. coli. These results therefore confirm the effectiveness of rice husk charcoal additive on improvement of composting process, it would be practically considered for treatment and management of fecal sludge.

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Chapter 4: THE OPTIMIZATION MIXING RATIO OF HUMAN FECES WITH RICE HUSK CHARCOAL

4.1. Introduction

Agriculture field has been the most popular work with high popular density since ancient in the Asia countries. Many traditional methods and techniques were developed to improve the productivity of crops, especially rice. The best way for raising the crops productivity was enhanced the fertilizer quality. Any available organic wastes such as human and livestock excretions, straw, leaf litter, grass, sewage, rice husk charcoal, and wood ash were treated and utilized as fertilizer for agriculture field and garden also (Hijikata et al. 2015, Austin 2008)

Among these additives, the amendment of bio-charcoal, which can be made from agricultural waste and wood waste, has benefits for agricultural production such as increasing the mineral supply, improving soil fertility, buffering the soil pH, reducing the exchangeable aluminium ion concentration, modifying water retention, promoting aggregate soil (Blackwell P 2009). The information leads to that bio-charcoal can be used as additive for composting toilet and that the produced with it would promote plant growth. Rice husk charcoal was also the popular amendment for soil in the Asia countries. The practice of using rice husk charcoal mixed with excreta had been very popular in wheat cultivation until about

100 years ago. There were double benefits, which are that the charcoal can absorb and retain chemical nutrients as well as deodorise excreta (Ogawa and Okimori 2010).

Due to the unavailability of rice husk charcoal locally and adapt composting toilet, rice husk charcoal amount used for composting toilet need to investigate for highest efficiency. The aim of this chapter investigated the changes in term of decomposition organic matter and reduction of nitrogen loss of composting of human feces with rice husk charcoal with different mixing ratio.

4.2. Materials and methods

4.2.1. Rice husk charcoal production

In this chapter, human manure (obtained from separated toilet “ECOSAN” in Seoul, Korea) were mixed with rice husk charcoal (dried rice husk was burned inside a close stainless steel fixed bed reactor of dimensions 0.5m x 0.2m x 0.15m for 2 hours to make rice husk charcoal) to simulate the composting process in lab scale.

Dried rice husk

Rice husk burning

Final product (rice husk charcoal)

Figure 4.1: Rice husk charcoal production

4.2.2. Composting experiment design

Composting process was monitored during 30 days in five plastic composting buckets at room temperature being 25^{o}C. The aeration condition was maintained during composting process by making the holes in surround and bottom of buckets with holes dimension and intensity being 3 mm and 2 holes per cm^2, respectively (similar with experiment in chapter 2). The composts were not turned during monitoring period. Triplicate compost samples were carried out from the five composting buckets for analysis on date of 1, 3, 7, 14, 21 and 30. Samples were taken from a half of the depth in composting buckets.

Table 4.1:

Summary of composting conditions for optimize mixing ratio

Items	**Value**
Monitoring duration	1 months
Turning	No turn
Buckets volume	5 L
Temperature	~25^{o}C
Mixing ratio (F:RHC)(v/v)	1-0.3; 1-0.5; 1-1; 1-2; 1-3
Sample days	1– 3 – 7 – 14 – 21 – 30

4.2.3. Measurement of materials chemical and physical properties

Physical and chemical properties (i.e. temperature, moisture content, organic matter, pH, total nitrogen and NH_4 –N) of raw material and its change in compost properties during composting process in five composting bucket were measured following the (George Estefan 2013) (Chapter 2.2.3). Based on the N concentration and the total bucket dry mass before and after composting, the actual N loss could be obtained. The actual N amount was calculated by multiplying the N concentration and the total bucket dry mass of the composting material. The actual N loss was the difference between the initial N amount and the final N amount in the composting materials. Decomposition rate of fecal matter was calculated based on the reduction of organic matter during composting process.

$$D_r = \frac{OM_0 - OM_t}{OM_0}.100 \quad \text{(ep.2)}$$

Where, OM_0 (%) and OM_t (%) are the organic matter content at time 0 and t, respectively, D_r (%) is the decomposition rate of organic matter.

4.3. Results and discussion

4.3.1. Environment factors changing

Shown in Figure 4.2, during the first week of composting process, temperature in five buckets rapidly increased and reached a peak from ambient temperature. However, the value of highest temperature was significant difference in composting bucket of mixing ratio 1:3 (30^{o}C) comparing with other buckets. The order of highest temperature in five composting buckets were following 1:0.3 > 1:0.5 > 1:1 > 1:2 > 1:3. This was due to the higher available organic matter at the initial material of composting (as seen in Table 1), which indicated a better condition for the growth and biological activity of microorganisms.

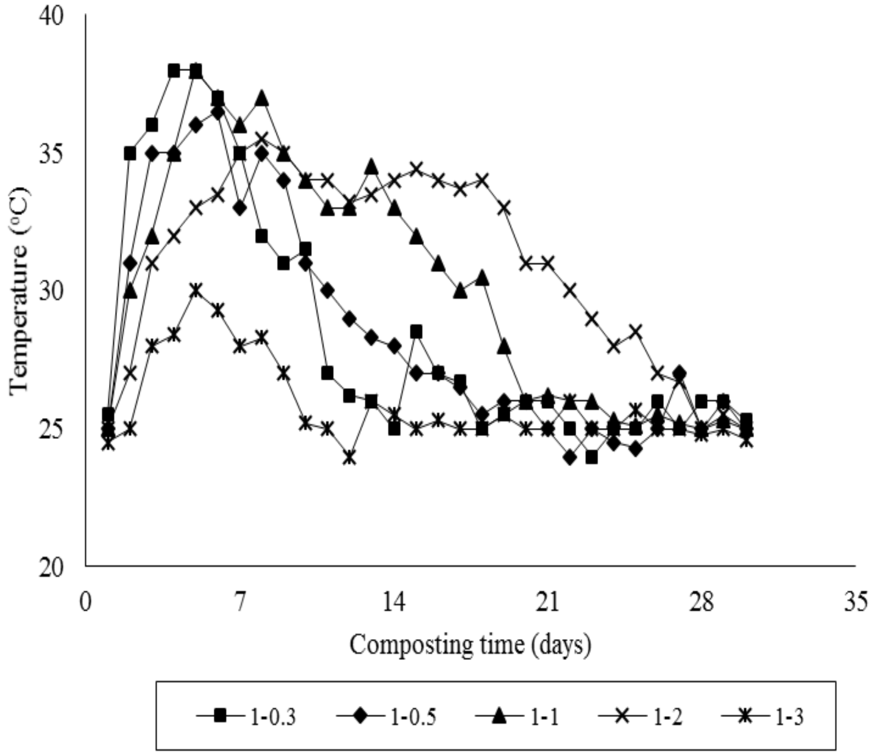

Figure 4.2: Changing of temperature during decomposition of different mixing ratio of feces and rice husk charcoal

The results in Table 4.2 showed that the amount of pH and moisture content in five mixing ratio composting buckets at the initial time and final time of process. Using of rice husk charcoal as the method to control of pH value and moisture content in composting process. Rice husk charcoal can be used as great method to control of the pH value (range from 7.3 to 9) as well as moisture content (range from 41% to 71.4%) by changing amount of rice husk charcoal for mixing with human feces.

Table 4.2:

Changing of moisture content and pH during composting process in different mixing ratio of feces and rice husk charcoal

Mixing ratio	Initial time		Final time	
	pH	Moisture (%)	pH	Moisture (%)
1 - 0.3	7.3	71.4	7.5	62
1 - 0.5	7.9	67.5	8.2	59
1-1	8.3	59	9	50
1-2	8.7	52	9.2	51
1-3	9	41	9.3	37

4.3.2. Decomposition of organic matter

In this chapter, organic matter content reduction was used as indicators to estimate the impact of different mixing ratio between human manure with rice husk charcoal on decomposition fecal matter. Shown in Figure 4.2, the amount of organic matter content in five composting buckets was gradual reduction following the reduction of human manure amount in difference mixing ratio with the order of mixing ratio 1:0.3(68%) > 1:0.5(61%) > 1:1(57%) > 1:2(53%) > 1:3(47%). Especially in composting bucket of mixing ratio 1:1, organic matter was reduced significantly high comparing with other mixing ratios buckets (Figure 4.2). As can be seen in Figure 4.3, decomposition rate of organic matter in five composting buckets were significantly high during first week of composting period compared with other time. The most effective in term of decomposition organic matter was shown in the bucket with mixing ratio 1:1 (33%) and the other mixing ratio following the order 1:2 (28%) > 1:0.5 (23%) > 1:0.3 (16%) > 1:3 (10%).

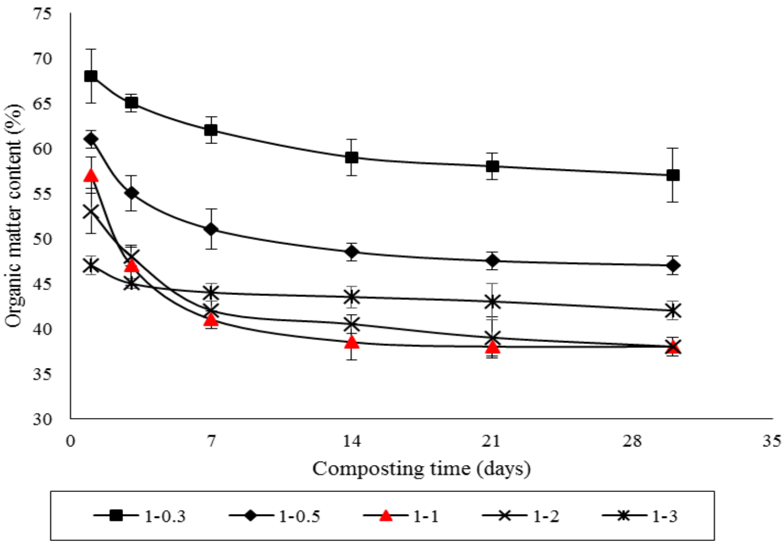

Figure 4.3: Organic matter changing during decomposition of different mixing ratio of feces and rice husk charcoal

The reason for the different of decomposition rate in five buckets can be explained by the impact of moisture content in buckets. The relationship between moisture content and decomposition rate was presented in Figure 4.5. In detail, the decomposition of organic matter occur under the operation of microorganism bacteria. Environment factors therefore impact to the activities of microbial such as temperature, moisture content, particle size, aerobic condition, nutrient balance and pH. The change in these factor can be the reason for the difference effective of decomposition (Horisawa et al. 2000). Among these factor, moisture content was the essential factor which need to manage in term of design as well as operating composting process to optimize the effort of decomposition. Because aerobic decomposition of organic matter depends on the presence of water to support microbial activity as well as the transformation of nutrient in compost (Richard et al. 2002). If moisture content get high level, water will displace much of the air in the pore spaces in the compost bucket lead to reduction of decomposition organic matter. On the other hand, if the moisture levels drops the nutrients are no longer in an aqueous medium and not easy available to the microorganisms(Zavala and Funamizu 2005), especially in this case of no turning composting buckets. Shown in Figure 4.5, the optimum moisture content for decomposition organic matter should range from 55% - 60%.

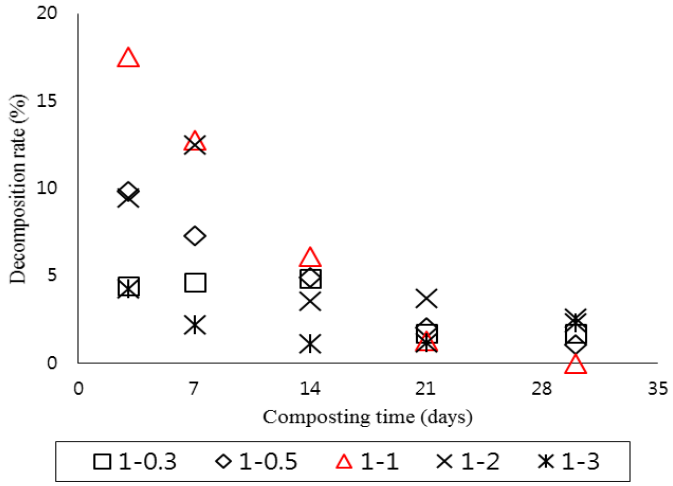

Figure 4.4: Decomposition rate changes during decomposition of different mixing ratio of feces and rice husk charcoal

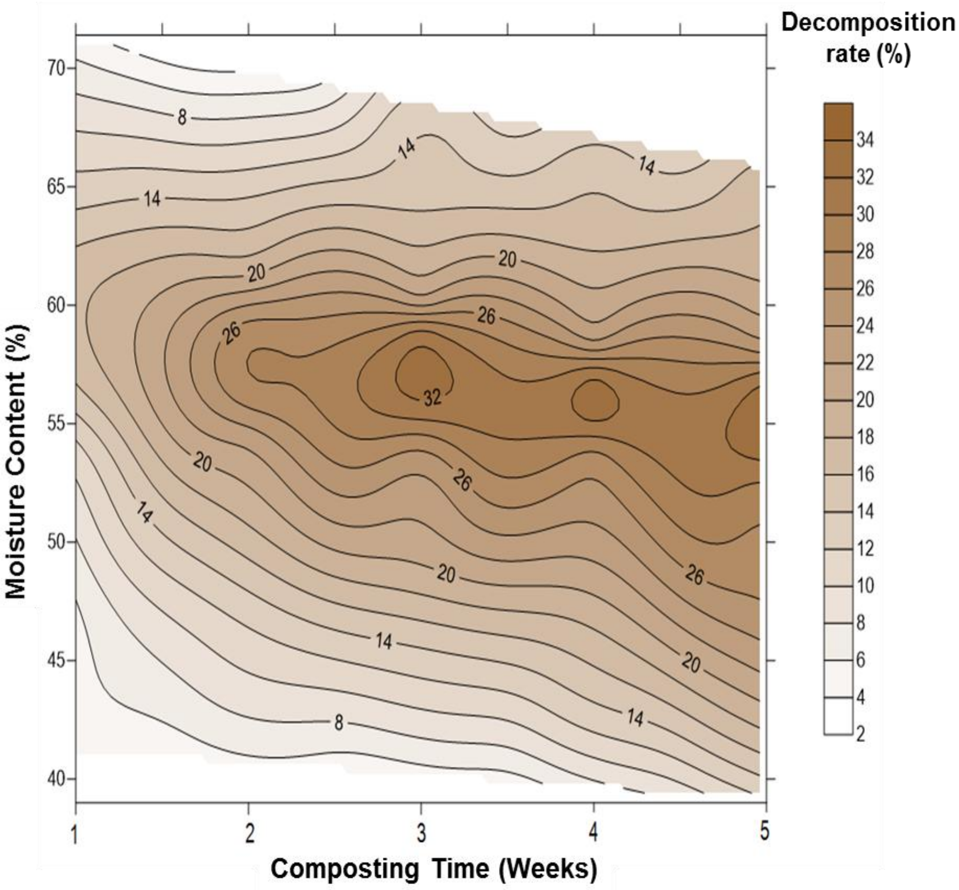

Figure 4.5: Relation between moisture content with decomposition rate during composting

4.3.3. Nitrogen conservation

Trends of total nitrogen changing during composting period was varied in five composting buckets. Total nitrogen content in the composting buckets for mixing ratio with low amount of rice husk charcoal being 1:0.3 and 1:0.5 decreased during the thermophilic phase and then gradually increased until the end of process. In term of other mixing ratio with high amount of rice husk charcoal being 1:1, 1:2 and 1:3, total nitrogen content gradually increased over the entire composting process (Figure 4.6). The reason for rising of total nitrogen content in buckets with mixing ratio 1:1, 1:2 and 1:3 were the loss of dry mass by the emission of carbon dioxide as well as water evaporation by heat under organic matter mineralization of microorganism bacteria (Inoko et al. 1979). However, the raising of total nitrogen content in buckets with mixing ratio 1:1 and 1:2 seemed much more than in mixing ratio 1:3. This phenomenon due to the decomposition rate of organic matter in buckets with mixing ratio 1:1 and 1:2 higher than 1:3 (chapter 4.3.2).

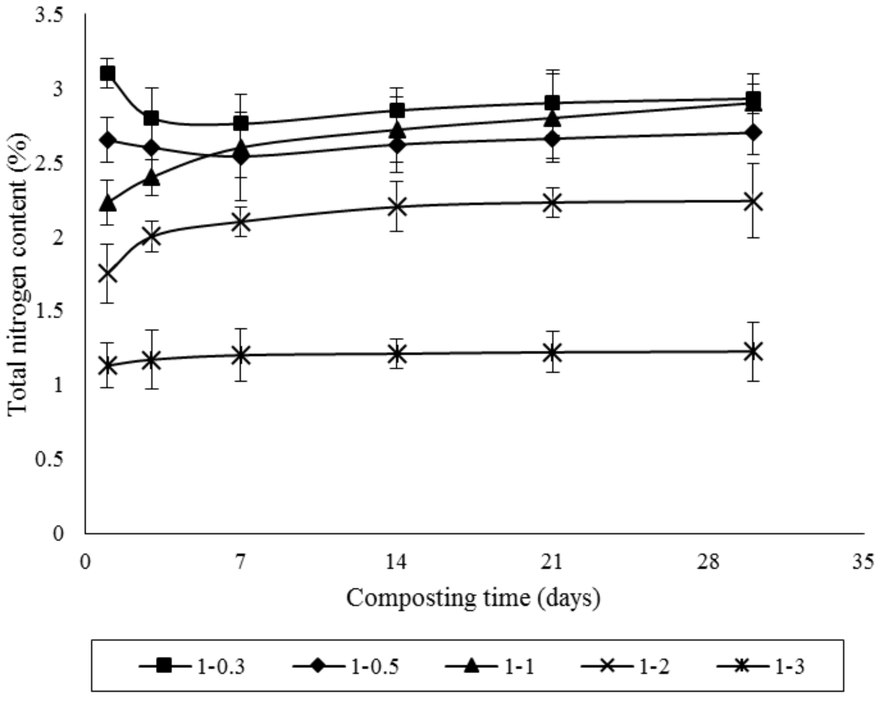

Figure 4.6: Changing of total nitrogen content during decomposition of different mixing ratio of feces and rice husk charcoal

The total nitrogen loss was calculated based on the dry mass balance after composting decreased with an increasing amount of rice husk charcoal additives. Amount of total nitrogen loss was highest in composting bucket with mixing ratio 1:0.3 being 10.17 g, whilst total nitrogen loss in the composting bucket with mixing ratio 1:3 was 3.95 g. However, the different of total nitrogen loss rate in three composting bucket with mixing ratio 1:1, 1:2 and 1:3 were similar 15.9%, 15.5% and 15.2%, respectively (Table 4.3).

Figure 4.7, during the first week, NH_4 –N concentration of five composting buckets increased significantly and reaching peak values being 2210 $mg.kg^{-1}$, 2100 $mg.kg^{-1}$, 1700 $mg.kg^{-1}$, 1100 $mg.kg^{-1}$ and 810 $mg.kg^{-1}$ for the mixing ratio of 1:0.3, 1:0.5, 1:1, 1:2 and 1:3 respectively. Based on the results from previous research (Mahimairaja et al. 1994) the ammonification occurred to an increase in temperature and pH in thermalphilic phase, as well as the mineralization of organic-N compound. After thermalphilic phase, NH_4 –N concentration decreased significantly until the end of process because of the volatilization ammoniac. The Figure 4.8 presented the situation of nitrogen content in different F–RHC mixture ratio during composting period with numbers inside the diagram are nitrogen content in percent. Results show that mixing ratio of 1-1 can reach to the highest amount of total nitrogen content. Therefore, mixing ratio of 1-1 is the optimum ratio for nitrogen conservation

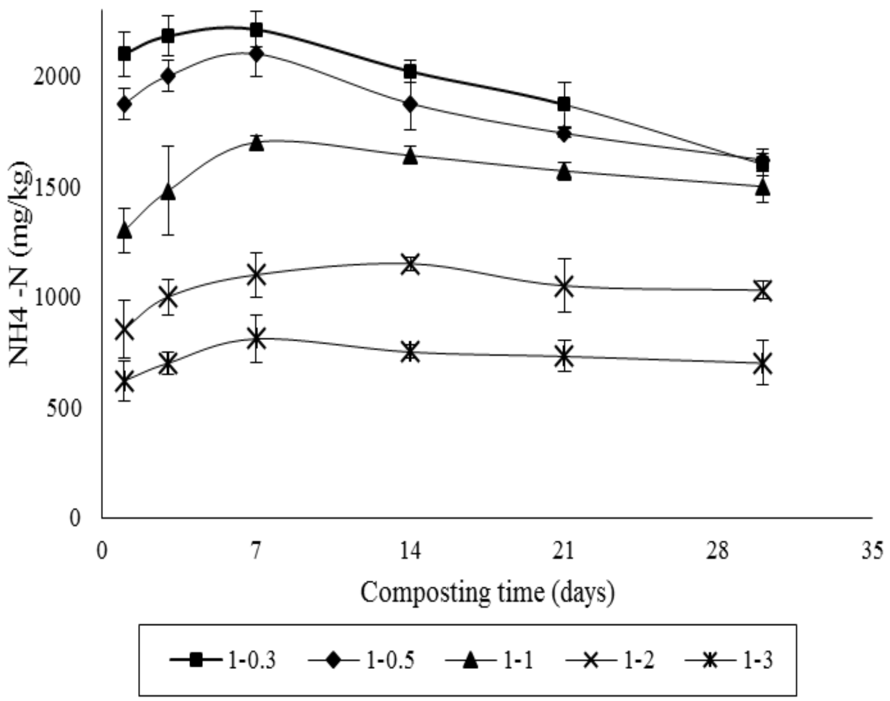

Figure 4.7: Changing of NH_4 -N during decomposition of different mixing ratio of feces and rice husk charcoal

Table 4.3:

Mass balances and nitrogen loss during composting process of different mixing ratio between human feces with rice husk charcoal

Mixing ratio (F-RHC, v/v)	Initial compost				Final compost				Nitrogen mass loss (g)	Nitrogen loss rate (%)
	Wet mass (kg)	Dry mass (kg)	Total nitrogen content (%)	Nitrogen mass (g)	Wet mass (kg)	Dry mass (kg)	Total nitrogen content (%)	Nitrogen mass (g)		
1 - 0.3	5.06	1.45	3.1	44.88	2.96	1.18	2.93	34.71	10.17	22.7
1 - 0.5	4.73	1.54	2.65	40.69	2.9	1.19	2.7	32.13	8.56	21
1 - 1	4.12	1.69	2.23	37.71	2.18	1.09	2.9	31.71	6	15.9
1 - 2	3.52	1.7	1.75	29.61	2.28	1.11	2.24	25.01	4.6	15.5
1 - 3	3.19	1.88	1.3	24.47	2.32	1.69	1.22	20.75	3.95	15.2

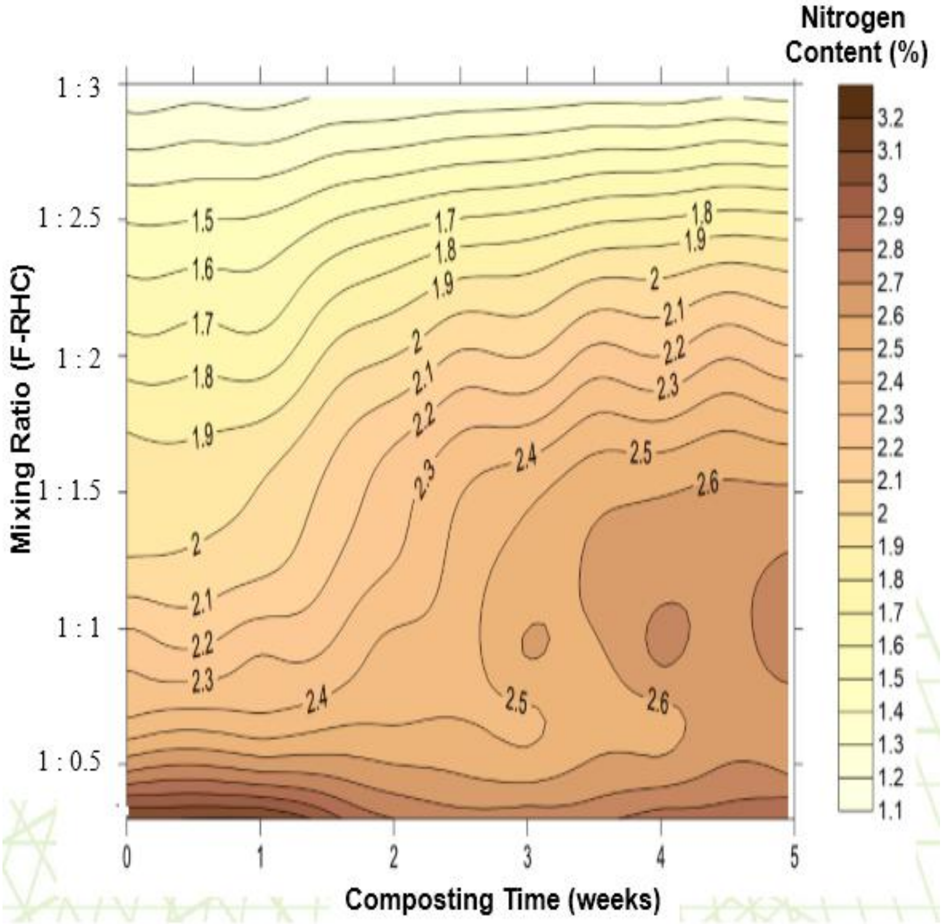

Figure 4.8: Relation between mixing ratio with total nitrogen content during composting

Summary

This chapter optimized the mixing ratio of human feces with rice husk charcoal for improvement of decomposition organic matter and reduction of nitrogen loss also. Among five types of mixing ratio being 1:0.3, 1:0.5, 1:1, 1:2 and 1:3, composting bucket with mixing ratio of 1:1 presented the most effective for decomposition of organic matter with decomposition rate being

33%. For reduction of nitrogen loss, the results shown the total nitrogen loss rate similarly in three mixing ratio 1:1, 1:2 and 1:3 with the value being 15.9%. 15.5% and 15.2% respectively.

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Chapter 5: CRITERIA FOR GOOD COMPOSTING PROCESS

5.1. Selection of criteria for additives

The composting is a biological process that involves the aerobic decomposition of organic matter to produce a humus-like product called compost. During the composting process, heat, various gases and water vapour are released, greatly reducing the volume and mass of the composting buckets. The concept of establishing standards specific to compost and the promotion of quality criteria in order to bolster the compost industry and to aid growth of new markets has been slowly emerging over nearly two decades throughout the western world. Recently, several European countries have adopted specific standards and many other countries are in the process of doing so. In the United States, efforts have been very scattered.

There is no simple way to give a summary concerning compost quality standards as they exist in the world, and how they arose. This study is based on the experiment results to make the criteria for good composting to estimate the effort of different additives application for composting toilet.

There were two parameters indicated to estimate the effort of different additives being pH and nitrogen loss rate during composting process in term of removal pathogen bacteria, reduction of excrete smell and keeping nitrogen.

According to removal of pathogen bacteria, pH is the important factor effect to the pathogen bacteria as well as microorganism bacteria. The alkaline environment has an effectiveness on pathogen die-off, pH value of 9 and above could be optimal condition to removal of pathogen bacteria. However, too high pH can become the reason of good microorganism bacteria inactivation lead to the ineffective of composting process. Therefore, range of pH from 9 to 10.5 is optimal for performance of composting process (WHO 2006)

For the operation of composting toilet, reduction of excrete smell is the big challenge, because it directly impact to the user. In addition, nutrient is the important part of compost and ability for application. Therefore, keeping of nitrogen in compost is the important mission of additives, keeping nitrogen in compost lead to improve the compost quality as well as reduction of excrete smell, because lager amount of nitrogen loss by the volatilization of ammoniac which is one reason of excrete smell (Martins 1992).

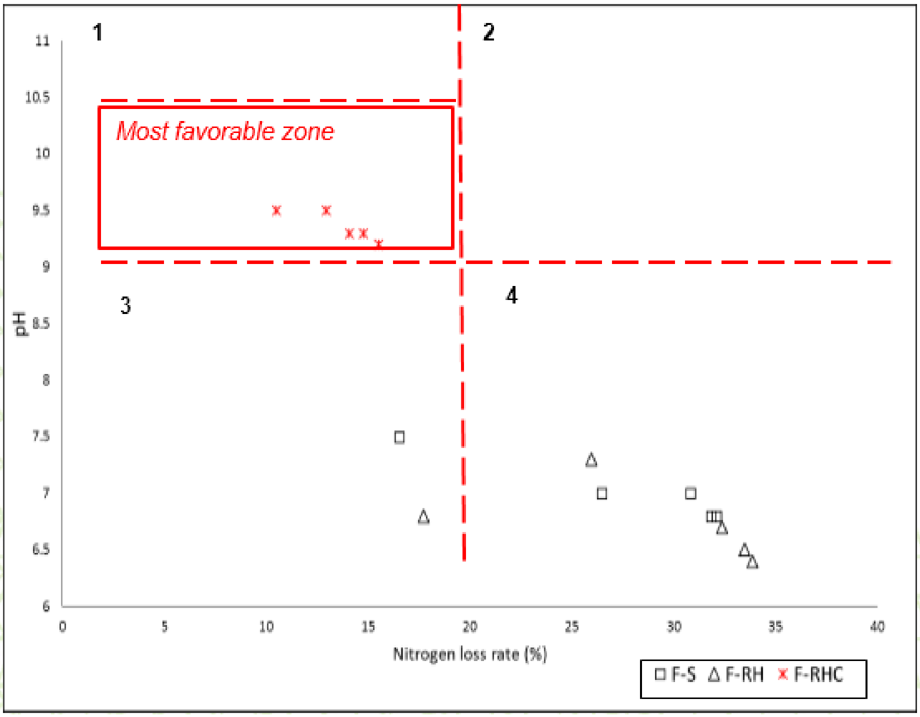

Figure 5.1: Selection of criteria for additives

From experiment results, the criteria for additives can be suggested with four zone 1, 2, 3 and 4, with zone 1 is the moist favorable zone for improvement performance of composting process. This graph can be used as a criteria for judging about the performance of additives for composting.

- Results show that composting condition with rice husk charcoal in the most favourite zone.
- The efficiency of sawdust and rice husk need to improve.

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Chapter 6: CONCLUSIONS

The conclusions of this research are as follow:

1. This research compared removal efficiencies such as decomposition of organic matter, reduction of nitrogen loss and pathogen bacteria removal of differing additives when mixing with human feces in composting toilet. The simulation of composting process was taking place in laboratory with 5L composting bucket. The results shown the unsurpassed of rice husk charcoal comparing with rice husk and sawdust. Mixing of human feces with rice husk charcoal can enhance the decomposition of organic matter, reduction of nitrogen loss from feces, as well as instantiate removal of pathogen bacteria by giving high pH level for mixture, demonstrating that rice husk charcoal can be the suitability additive for the operation of composting toilet.

2. In this study, for improvement of composting toilet operation, the difference mixing ratio of human feces with rice husk charcoal also investigated in term of decomposition organic matter and reduction of nitrogen loss. The results shown the most effective for improvement of decomposition organic matter in mixing ratio 1:1. In term of reduction of nitrogen loss, total nitrogen mass loss was reduced when increasing amount of rice husk charcoal using. Interestingly, in comparison between three buckets with mixing ratio 1:1, 1:2 and 1:3, the total nitrogen loss rate were similar 15.9%, 15.5% and 15.2%, respectively.

From this results, mixing ratio 1:1 would be the best compromise to optimize the process and obtain a high quality compost.

3. In addition, the results from this study indicated the criteria of an efficient composting toilet in the presence of different additives based on pH value and total nitrogen loss rate during composting process

퇴비화 변소에 적합한 첨가물의 선택

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이 연구는 인간 배설물과 다양한 첨가제를 섞어 퇴비화 효과를 개선시키는 것을 다룬다. 고려하는 요소는 유기물을 분해 효율을 강화, 질소 유실의 감소, 세균 감소다. 첨가제 세 가지는 한국에서 구입가능한 톱밥, 쌀겨, 쌀겨숯이며 사람의 대변과 2:1의 비율로 섞었다. 퇴비화를 위한 쌀겨숯과 대변의 최적 혼합비율 역시 계산하였다. 원재료의 특성과 공정 중 퇴비화 특성은 수분함량, pH, 유기물 함량, 총 질소, NH_4 –N, E.Coli 농도로 측정하였다. 퇴비화 통 유기물의 분해율은, 대변/톱밥의 경우 13.4 %를, 대변/쌀겨의 경우 18.6 %를, 대변/쌀겨숯의 경우 32 %를 나타냈다. 대변/쌀겨숯의 경우 총 질소 함량은 1.9 % 에서 2.25 % 로 시간이 지날 수록 올랐다. 하지만 대변/톱밥과 대변/쌀겨의 경우 2주 동안 줄어들었다. E. Coli농도는 세 가지 경우에서 모두, 첫 주가 지난 이후에 급격히 줄어들었다, 흥미롭게도 대변/톱밥과 대변/쌀겨의

경우에서는 2달이 지나도 완전히 제거하지 못했던 E. Coli가 대변/쌀겨숯의 경우에서는 5주가 지난 후부터는 전혀 발견되지 않았다. 이러한 결과는 유기물분해, 질소유실 방지, 세균감소의 측면에서 대변/쌀겨숯의 혼합이 퇴비화 효과를 강화하는데 효과적이라는 것을 보여준다.

퇴비화를 최적화 하기 위해, 대변과 쌀겨숯의 혼합비율을 연구하였다. 대변과 쌀겨숯의 혼합비율을 각각 1: 0.3, 1: 0.5, 1:1, 1:2, 1:3 으로 하여 랩스케일 반응조에서 호기조건하에 섭씨 25도 조건에서 30일간 배양하였다. 유기물 분해율은 1:1 혼합조건에서 33 %로 가장 높았고, 1:3 조건에서 10.6 %로 가장 낮았다. 질소유실질량은 쌀겨숯의 혼합비가 높을 수록 줄어들었지만 1:1, 1:2, 1:3의 경우에서 유실비율이 각각 15.9 %, 15.5 %, 15.2 %로 그 차이가 크지 않았다. 따라서, 쌀겨춧의 첨가가 퇴비화 공정에 긍정적이면서도 부정적으로 영향을 미칠 수 있으므로 1:1의 혼합비가 가장 적절하다.

Keywords: Composting toilet; rice husk charcoal; pathogen bacteria; organic matter decomposition; nitrogen loss

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