Evaluation of Effect of Cover Soil Application on Leachate Quantity and Quality under the Tropical Climate Condition

熱帯気候条件での覆土の浸出水量・水質への影響の評価

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Interdisciplinary Graduate School of Agriculture and Engineering
Department of Environmental and Resource Sciences
University of Miyazaki

Tri Budi Prayogo

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Chapter 1 General Introduction

1.1 Background

Over the years, municipal solid waste (MSW) management has been undertaken using many different approaches worldwide (Chowdury, 2009). The management of MSW has become a critical issue in many countries. The progress of modern civilization and the associated increase in the worldwide population has contributed significantly to the increase in the quantity and variety of waste generated (Turan et al., 2009). In developing countries and developing areas with mixed economies such as the Asian region, municipal authorities lack the resources and trained staff needed to provide their rapidly growing populations with the necessary facilities and services for solid waste management to support an adequate quality of life (Bartone et al., 1994). A general concern of the entire solid waste management system in developing countries is the problem of landfill development and management (Idris et al., 2004). In addition, climatic factors play a crucial role in the management of MSW, e.g., most countries in Asia are located in tropical or sub-tropical zones with long wet seasons, high heat and humidity (Visvanathan et al., 2003).

Leachate production and management is now recognized as one of the greatest problems associated with the environmentally sound operation of sanitary landfills. The leachate problem is made worse by the fact that many landfill sites still operate without an appropriate impermeable bottom liner or an effective collection and subsequent treatment system for landfills. In addition, a major constraint to the successful treatment of landfill leachates is the difficulty in identifying and quantifying the typical composition characteristics of the waste contained in the landfill (Tatsi et al., 2002)

Similar to other countries in the Asian region, Indonesia recently faced a solid waste management problem. On average, every Indonesian generates 0.76 kg of solid waste per day. Thus, Indonesia would generate 187,366 tons of municipal solid waste per day (MoE, 2008). Indonesia is still struggling to decide on the best option to treat and dispose of the waste. The obstacles to improving waste management include financial constraints, low waste management literacy of the population, a lack of cooperation between the public and private sector and limited availability of trained and skilled personnel in the waste management sector (Mrayyan et al., 2006).

Due to the solid waste management situation, insufficient landfill sites with appropriate leachate treatment, and the climatic conditions, Indonesia is faced with the problem of increasing the MSW service and leachate treatment at landfill sites. Therefore, Indonesia need an evaluative approach such as a strengths, weaknesses, opportunities and threats (SWOT) analysis to solve the solid waste management problem In addition, an approach that can be used to predict the quantity and quality of the leachate for planning leachate treatment plants is needed.

1.2 Literature Reviews

1.2.1 SWOT Analysis

A SWOT analysis is a technique that is commonly used to assist in identifying strategic direction for an organization or practice. The strengths and weaknesses of a system are determined by internal elements, whereas external forces dictate opportunities and threats. Strengths can be defined as any available resource that can be used to improve the performance of a system. Weaknesses are flaws/shortcomings of a system that may result in the loss of a competitive advantage, efficiency or financial resources (Paliwal, 2006).The SWOT analysis is widely recognized and it constitutes an important basis for learning about asituation and for designing future procedures and can therefore be seen as necessary for thinking in a strategic way (Lozano et al., 2006).

A SWOT analysis was performed to formulate strategic action plans for the management of MSW in order to mobilize and utilize the MSW resources, raise inhabitant awareness, and utilize the municipal corporation’s resources. This has allowed the introduction of a participatory approach for better collaboration between the community and the municipal corporation. Using a SWOT analysis, efforts were made to explore the ways and means of converting the possible ’threats’ into ‘opportunities’ and changing the ‘weaknesses’ into ‘strengths’, with respect to future implementation of MSW management programs (Srivasta et al.,2005)

As one of the developing countries that is still struggling to decide on the best option to treat and dispose of waste, Indonesia continues to face obstacles to improve waste management. These obstacles include low waste management literacy in the population, a lack of cooperation between the public and private sector and limited availability of trained and skilled personnel in the waste management sector (Mrayyan et al., 2006). It appears that the socio-economic status of a city is positively correlated with the technical competence of the waste administrators (Chung et al., 2008) and may determine the attitudes of the inhabitants, such as their ability/willingness to recycle (Rotichet al., 2006)and knowledge of how or where to recycle solid waste (Aljadarin et al., 2011).

In Indonesia, a SWOT analysis was widely implemented for the management of solid waste. The focus of the analysis was to evaluate the performance of the Malang Municipality in terms of waste management. The collection, transportation method, and landfill management were some issues that were discovered in the analysis. Strategies to improve the management process and to prevent factors that inhibit the treatment of waste in the landfill were focal points of the SWOT analysis (Kosmanto et al., 2010).

Since the Malang Municipality in Indonesia still faces common solid waste management problems such as public awareness, economic trends, changes in the population, open dumping disposal method, and segregation of the waste collection system, it was necessary to evaluate the performance of the solid waste management using a SWOT analysis. As a rapidly growing city, the Malang Municipality has unique problems relating to the population, culture, social character, background education and the perception of solid waste management. The other consideration was the regions surrounding this area that are less developed and therefore depend on this municipality. The investigation combined these aspects to produce a strategy that could be implemented in this municipality and expanded to other municipalities in Indonesia that had similar problems in their solid waste management systems.

1.2.2. Prediction of Leachate Quantity

The quantity of leachate produced by a landfill is highly correlated with the amount of precipitation in and around the landfill area. In areas with high precipitation rates, the production of leachate can be greater than in drier areas since much of the precipitation percolating through a landfill becomes leachate (Tasti et al., 2002).

Several predictive models that use different approaches are often used to calculate the quantity of leachate. Leachate prediction models have been developed using mathematical modeling, a stochastic method, and a numerical process combined with a hydro-physical model and the hydraulic properties of the waste (Zacharof et al., 2003; Felner et al., 2010; Joshoua et al., 2012; Demirekler et al., 1999). Some researchers (e.g., Ojoawo et al., 2012, Oni et al., 2010, Johnson et al., 2001 and Rosquist et al., 2000) used a dynamic system, probabilistic models and a neural networks approach to examine water flow in the waste to show the uncertainty of the predicting process. Capelo et al. (2007) reported the results of an experimental approach that used the hydraulic conductivity of the waste as the basis for a predictive model.

Water balance models are commonly used to predict the quantity of the leachate. Engineering software using a water balance approach has been developed to understand processes that occur in a landfill site. Software such as the as Hydrologic Evaluation of Landfill Performance (HELP) model and a Two-dimensional Water Balance Model for Waste Heaps (BOWAHALD) models are widely used to predict the amount of leachate generated, which depends on the hydrological processes at the landfill site (Dovenska et al., 2009; Zeh et al., 2003; Dho et al., 2005). The effect of the climatic conditions on landfill processes have been reported (Trankler et al., 2001; Tatsi et al., 2002).The most frequently adopted model is the HELP model. This model needs detailed on-site morphology data and extensive hydrology data to calculate the water balance. This model is useful for the long-term prediction of the leachate but is not suitable for the prediction of daily leachate production (Worell et al., 2011).

Based on the results of the water balance, it was concluded that leachate generation was affected by:

- Climatic conditions (rainy season and dry season): rainfall patterns affect leachate generation. During the dry season, when there is less or no precipitation, a small amount of leachate is generated and there is less accumulation of the leachate or a stagnant discharge. During the rainy season, which normally has intensive rainfall, more leachate is generated and there is higher accumulation than in the dry season. Furthermore, the leachate characteristics fluctuated with the phase of decomposition and the rainfall pattern.
- Design of the top cover layer (e.g., standard cover, alternative cover or no cover): an open dump only has a thin sand cover, which produces high levels of leachate due to high water infiltration.
- Properties of the MSW input (i.e., pre-treated waste, MSW compaction, moisture content of the incoming MSW, etc.) (Teresa et al., 2003).

In Indonesia, an estimate of the amount of leachate generated ,as mentioned in the Indonesian National Standard for the construction and operation of landfills (MoE, 2001), focused on the sanitary landfill type, where a cover soil was used in the landfill. The calculation of the leachate generated was based on a water balance method using the HELP model.

The standard does not allow the amount of leachate generated to be predicted for an open dumping landfill system. Some study was focused on the evaporation of the cover soil connected with the rate of infiltration that entered to waste body (Samin et.al, 2012) focused on the evaporation from the cover soil that was related to the rate of infiltration into the waste site.

In the literature, limited information exists on the interaction between a tropical climate and leachate composition and generation, especially for open dump sites. In addition, because of the number of open dumping landfill sites and the commonly used method to predict the generation of leachate in Indonesia, it is necessary to establish a method to predict the amount of leachate generated for open dumping sites that accounts for the climatic conditions and considers leachate production on a daily basis.

1.2.3. Prediction of Leachate Quality

Prediction of leachate quality is related to the waste biodegradation process in the landfill. The quality of leachate from a landfill dominated by organic waste is affected by biological degradation. Biodegradation is affected by chemical and physiological factors in the environment, such as the oxygen concentration, temperature, pH, and salinity. In addition, one of the most significant environmental factors that influence biodegradation is the water content. With an increase in water content, there is higher activity of microorganisms due to better transport conditions for the nutrients and an increase in the amount of dissolved substances (Najarno et al., 2004).

The optimum conditions for the enzymatic and hydrolytic degradation of high-molecular organic compound materials occurs at a water content above 65%, and for composting bulk material, the value is close to its water holding capacity, which rangesfrom60% to over 80% (Ahn et al., 2008; Zang et al., 2007; Berriel et al., 2008). By artificially adjusting the moisture content to values just below water holding capacity, biodegradation and the energy production rate in the initial composting period can be improved. At low water contents, i.e., below 20 mass per mass (m/m), the biological activities decrease to zero (Rodriguez et al., 2001).The production of methane (CH_4) is negligible when the water content of the soil is less than 23%. Methane production increases with the water content of the soil and reaches a maximum at 66.7% water.

When examining the effect of the water content on the biodegradation of landfill waste, few researchers have considered the critical water content, i.e., the water content below which biological activity is significantly reduced. The critical water content varies according to the material, composition and treatment of the waste. While the critical water content has not beenclearly described, the results show that the lower the water content, the slower the biodegradation process (Liang et al., 2003; Promier et al., 2009). Biodegradation under extreme changes in the water content, e.g., Under tropical climatic conditions, has been examined in some studies. In these studies, the quality of the leachate resulting from the biodegradation process varied seasonally (Visvanathan et al., 1999; Kawai et al., 2012).

The degradation of solid waste is a function of the water content. The degradation process can be described by first order kinetics and the water content is the most important factor influencing the reaction rate of degradation. An increase in the water content of the waste will accelerate the degradation process, which isindicated by an increase in the reaction rate (Qdaiset al., 2008; Kamalan et al., 2011). Leachate recirculation has been reported as a method that enhances the biodegradation rate. Experimental and field results of leachate recirculation studies show that the water content was increased as a result of leachate recirculation (Ozkaya et al., 2007; Kelly, 2002).

Some researchers propose using a model to predict the quality of the leachate from the landfill. Several methods have been used in the modeling approach to determine the quality of the leachate produced. Some models have been combined with leachate quantity prediction models, and in others, mathematical, finite element and statistical approaches have been introduced to show the correlation between the leachate quality and factors in the landfill that influence the quality of the leachate (Demirekler et al., 1999; Batht, 2013; Mirbagheri et al., 2008).A distributed model and simulation method have been proposed to predict leachate quality in areas subjected to specific conditions such as arid or moonsoning conditions (Trankler et al.,2001; Vavilin et al., 2006; Yaqout et al., 2003). The proposed models emphasize that the water content plays an important role in determining the quality of the leachate produced. Other factor such as type of the waste, its density and pretreatment are affect the degradation process. However, limited information exists on predictive models in tropical climate areas and the influence of the critical water content on the degradation process.

Given that climatic conditions influence the leachate quality and that limited information exists on the prediction of leachate quality based on the critical water content of the waste, the ability to predict the influence of climatic conditions on leachate quality is needed. Such a prediction will account for the role of the water content in the degradation process, especially the role of the critical water content as the basis for the initiation of the degradation process. This type of prediction can be combined with a water balance model to predict the quantity of the leachate.

1.3 Objectives of the Study and Structure of the thesis

The objectives of this research were to evaluate the solid waste management of the Malang municipality in Indonesia and to predict the quantity and quality of the leachate based on the climatic conditions. The results of this research will provide a useful basis to increase the performance of solid waste management and to develop a leachate treatment plant in Indonesia.

The initial aim of this study was to examine and evaluate the conditions of the solid waste management problems in Indonesia, especially in rapidly growing municipalities. The problems were analyzed using the SWOT analysis method, which was performed to formulate strategic action plans for treating MSW. This analysis evaluated the existing performance of the MSW management and investigated any shortcomings of the system that could be addressed. The following recommendations were proposed: increase the performance of the solid waste management system, including the landfill management, and increase the perception of the population.

The other objective of this study was to predict the leachate quantity and quality in a landfill. This study evaluated the effect of atop cover and an intermediate cover on the quantity and quality of the leachate (compared with the open dumping landfill system) using a simple method and prediction on a daily basis. In addition, this type of prediction can be used as an additional standard for the construction and operation of landfill sites in Indonesia where most landfill sites still use open dumping systems. The leachate quality prediction focused on the biodegradation of the organic material in the landfill site and was related to the critical water content of the waste. The prediction of the leachate quantity was related to the application of a cover soil, which was associated with the distribution and movement of water in the landfill as well as climatic conditions in Indonesia. Several experiments were conducted to simulate the degradation of the organic material and the distribution of water in the landfill site. The investigation examined the influence of the water content of the waste on the biodegradation process.

This thesis is organized into six chapters and has been written as a series of manuscripts that correspond to the objectives of this study. **Chapter1** provides a general introduction, including the background of the study; the literature survey, which includes the SWOT analysis; the prediction of the leachate quantity and quality; the objectives of the study and the structure of the thesis. **Chapter2** outlines the practice of MSW management in Indonesia, including the conditions of the solid waste management in Malang Municipality and its problems, and the SWOT analysis of the solid waste management. **Chapter3** provides the results of an investigation on the effect of the water content of the waste on the activity of microorganisms, including the experimental method used and results of the gas generated. **Chapter4**discusses the evaluation of the water content in the landfill layers in the dry season. **Chapter5** discusses the prediction of the leachate quality and generation in Indonesia. This chapter includes the development of a simple model of leachate quality and generation, and discusses leachate treatment in landfills with respect to conditions in Indonesia. **Chapter6** summarizes the general conclusions drawn from the results of the study.

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Chapter 2 SWOT Analysis of Municipal Solid Waste Management in a Growing City in Indonesia (Case Study of Malang Municipality)

2.1 Introduction

Indonesia, as a developing country in Southeast Asia, is growing rapidly and is facing various problems as a consequence of development. In most major cities in Indonesia, population increase has created poor environmental living conditions that significantly affect sanitary conditions. Of these problems, the most common in urban areas is currently the improper management of municipal solid waste, which is also a growing concern within those cities (Damanhuri et al., 2009).

The current practice of solid waste management in Indonesia, which focuses on ‘the end-pipe-approach’, causes problems at the final disposal site. Based on 2006 data from the Ministry of Environment, 60% of the landfills in Indonesia are close to the end-year-period (23% in the next year and 37% in the next five years). This could be a problem, because the planning and construction process of landfill sites cannot be accomplished in a short time period (MoE 2008). Many cities are facing the problem of overburdened landfills because of limited land availability and open dumping sites that are not equipped with sanitary systems (such as soil covers, leachate collection and treatment systems) and therefore pollute the environment through CH_4 emissions and leachate intrusion into the ground and surface water. Another constraint is inadequate waste management laws, which lead to inefficient solid waste management in Indonesia. The current laws do not specifically regulate the management of solid waste (Mediana 2010).

As a developing country that still struggles to decide on the best option to treat and dispose of waste and because of financial constraints, Indonesia continues to face low waste management literacy of the population, a lack of cooperation between the public and private sector and limited availability of trained and skilled personnel in the waste management sector as obstacles to improving waste management (Mrayyan et al., 2006). It was discovered that community support of waste management work was lacking. It appears that the socio-economic status of a city is positively correlated with the technical competence of the waste administrators (Chung et al., 2008) and may determine the attitudes of the inhabitants, such as their ability/willingness to recycle (Rotichet al., 2006)and knowledge of how or where to recycle solid waste (Aljadarin et al.,2011).

Some researchers successfully implemented a method to solve the solid waste management problem that was correlated with the conditions of each municipality or area. For example, response surface model (RSM) numerical simulations, (Shamshiry et al., 2010), a techno-economic (Qdais, 2007), a contingent valuation approach (Fonta et al., 2007), wasteful waste-reducing policies with processing costs (Jaeger et al., 2011), application of Analytic Network Process (ANP) and Decision Making Trial and Evaluation Laboratory (DEMATEL) software (Tseng, 2009) have been used to optimize and identify gaps in the solid waste management system.

Another method that can be used is a SWOT analysis. SWOT is an acronym for strengths, weaknesses, opportunities and threats. A SWOT analysis is a technique that is commonly used to assist in identifying strategic direction for an organization or practice. The strengths and weaknesses of a system are determined by internal elements, whereas external forces dictate opportunities and threats. Strengths can be defined as any available resource that can be used to improve the performance of a system. Weaknesses are flaws/shortcomings of any system that may result in a loss in a competitive advantage, efficiency or financial resource (Paliwal, 2006). The SWOT analysis is widely recognized and it constitutes an important basis for learning about a situation and for designing future procedures that can be seen as necessary for thinking in a strategic way (Lozano et al., 2006).

As a tool, a SWOT analysis can be used in business fields as well as other fields such as disaster and solid waste management (Na et al., 2009).There are several examples of successful applications of SWOT analyses in fields such as regional energy planning (Terrados et al., 2007), urban development planning (Halla, 2007), recycled water use (Mainali et al., 2007), environmental protection (Enache, 2010) and health care assessment (Waldau, 2007).

A SWOT analysis can be a useful tool for the strategic planning process of environmental management. However, this method has advantages and disadvantages. The advantages, for instance, may include the idea that this method is simple and that anyone can use it without having advanced knowledge or external technical support. The advantages of a SWOT analysis include the problem domain, multi-level analysis, data integration, cost, simplicity, and the analysis is application neutral. The disadvantages of this method include its simplistic, static, ambiguous and subjective character, and its lack of weighting factors. These short comings have influenced the transparency of the results of SWOT analyses (Nikolaou et al., 2009; Seker et al., 2012; Hong et al., 2010).

SWOT analyses have been performed to formulate strategic action plans for MSW management in order to mobilize and utilize resources and increase inhabitant awareness and the municipal corporation's resources. This has allowed the introduction of a participatory approach for better collaboration between the community and the municipal corporation. Using the SWOT analysis, efforts were made to explore the ways and means of converting the possible 'threats' into 'opportunities' and changing the 'weaknesses' into 'strengths' with respect to the implementation of future MSWM programs (Srivasta et al., 2005).

Malang Municipality is the second largest city in the East Java Province of Indonesia. This municipality covers 11,006 ha, lies at 440 to 667 m above sea level and has a population of 816,444 (Figure 2.1). Malang Municipality generates over 259,639 m^3 tons of waste (SoM 2007) and still faces common solid waste management problems such as public awareness (Aljadarin et al., 2011), economic trends, population changes (Dyson et al., 2005), the open dumping disposal method (Inanc et al., 2004), and segregation of the waste and collection system (Zia et al.,2009), similar to other municipalities in developing countries.

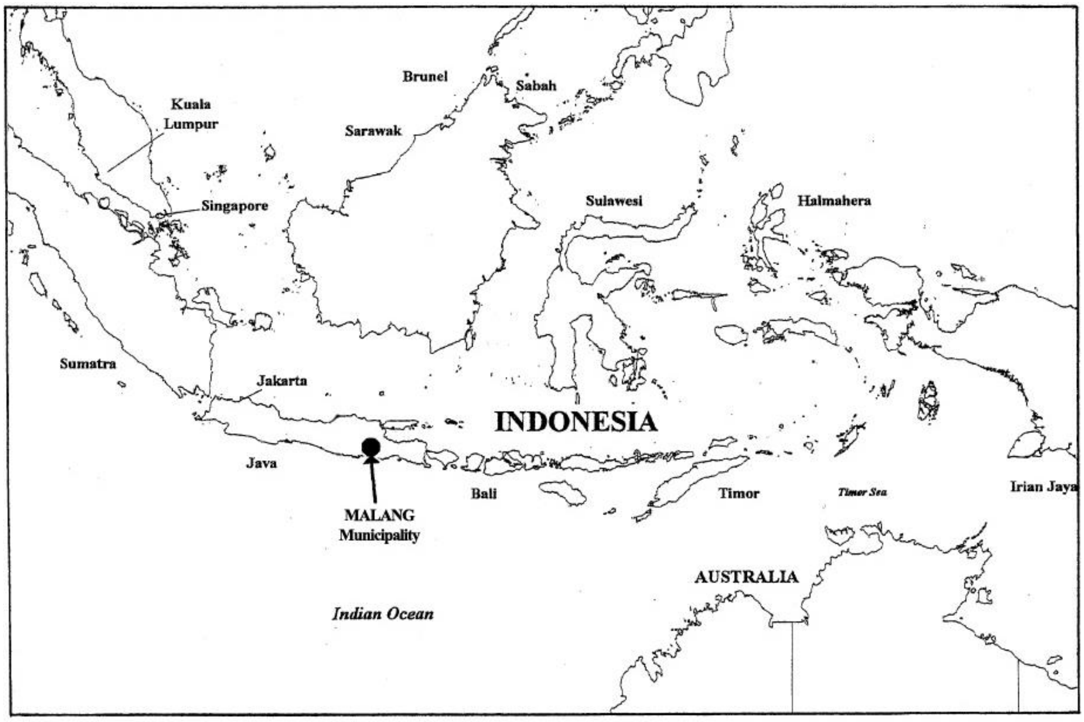

Figure 2.1. Malang Municipality Map

In this chapter, the strengths and weaknesses of the MSW management system, including the landfill management and the perception of the population were examined, as well as the opportunities and threats in the external environment. The intention was to develop strategic action plans for improved planning through an environmental and social-based SWOT analysis with a view to improve the solid waste management system in Malang Municipality.

2.2 Materials and Methods

Initially, a preliminary exploratory investigation of municipal solid waste management was carried out in this study, and data were collected before a detailed study was conducted, which was followed by a focused analysis using the SWOT method. For completing this methodology, three stages were implemented including a desk analysis and a field survey. The stages were:

Stage 1: This stage involved a desk study in which documents and records relating to the management of solid waste in Malang Municipality as well as statistical data on the flow of the waste generation, collection, transportation and disposal methods were obtained from the Malang City Waste Management Office (MCWMO). This stage included an interview with an MCWMO officer and the authority officer of the landfill site. Additional secondary data were obtained to support the data from other institutions in the municipality. These data were used to describe the conditions of the management system and to obtain background information and data to construct a conceptual model of the internal and external factors of the solid waste management in this municipality.

Stage 2: Afield survey was conducted based on interviews with residents of the area surrounding the landfill site (40 respondents) to evaluate the influence of the landfill on the people, and with residents of four different resettlement areas (250 respondents): the upper-class, middle-class, lower-class and rural resettlement areas to evaluate resident's perceptions of MSW management and their willingness to participate in the system.

Stage 3: Data compilation was conducted in this stage. The external and internal data of the solid waste management, the landfill site and the inhabitant's perceptions were analyzed with the SWOT analysis. The internal analysis was a comprehensive evaluation of the 'internal environments', i.e., the strengths and weaknesses, while the external analysis included the opportunities and threats that might arise when changes occur in the external environment during the implementation of the program. Pairwise comparisons were made between alternative strategies for all SWOT factors.

2.3 Results and Discussion

a. The Waste Collection in Municipality

Solid waste in Malang Municipality is collected from households, markets, public facilities, hospitals and other facilities by the MCWMO. The daily waste generated in this municipality was 3–4 liters/person/day. The average amount of solid waste collected from this municipality was 2,528 m^3/day. However, only 1,800 m^3 of waste was transferred to the landfill site every day. Household waste is collected in front of homes by workers using a 1 m^3 container and transferred to a temporary site (TPS). The waste collected at the TPS is transferred to the landfill. Market waste is collected by Market City Office workers collaborating with the MCWMO and transported directly to the landfill. Hospital medical waste is collected by hospital staff. The hazardous waste is treated at the hospital, and the non-hazardous waste is collected by the MCWMO and transported to the landfill. Waste from public and other facilities is collected by workers responsible for the MCWMO and sent directly to the landfill.

The data showed that only 71% of the population received solid waste services from the MCWMO. The transferred waste consisted of 69% residential waste and 31% non-residential waste. The density of waste at the landfill was 0.21–0.24 ton/m^3 with 81% organic waste and 19% inorganic waste. The inorganic waste consisted of 8% plastic, 4% rubber, 3% textile, 1% glass, and 2% other waste (Prayogo et al., 2008).

The data from the interview from the resettlement area are shown in Table 2.1 to Table 2.6

Table 2.1. Percentage of Age with Willingness to Segregate the Waste

Code	Age Category	Overall Precentage	Willing to Segregate	
			Yes	No
1	< 20	1,06%	0,00%	2,13%
2	20 - 30	4,73%	5,19%	4,26%
3	30 - 40	18,67%	18,18%	19,15%
4	40 - 50	45,95%	49,35%	42,55%
5	50 - 60	22,33%	23,38%	21,28%
6	> 60	7,27%	3,90%	10,64%

Table 2.2. Percentage of Knowing Reduce, Reuse, Recycle (3R) with Willingness to Segregate the Waste

Code	Knowing 3R Category	Overall Precentage	Willing to Segregate	
			Yes	No
1	Yes	41,93%	51,95%	31,91%
2	No	58,07%	48,05%	68,09%

Table 2.3. Percentage of Occupation with Willingness to Segregate the Waste

Code	Occupation Category	Overall Precentage	Willing to Segregate	
			Yes	No
1	Farmer	0,65%	1,30%	0,00%
2	Farmer worker	1,06%	0,00%	2,13%
3	Bussiness	5,14%	3,90%	6,38%
4	Worker	13,65%	3,90%	23,40%
5	Trader	13,00%	2,60%	23,40%
6	Government Employee	26,69%	36,36%	17,02%
7	Military	0,65%	1,30%	0,00%
8	Retired	4,73%	5,19%	4,26%
9	Other	34,43%	45,45%	23,40%

Table 2.4. Percentage of Education with Willingness to Segregate the Waste

Code	Education Category	Overall Precentage	Willing to Segregate	
			Yes	No
1	Not Educated	0,00%	0,00%	0,00%
2	Elementary	7,92%	5,19%	10,64%
3	Junior High School	6,62%	2,60%	10,64%
4	Senior High School	30,60%	20,78%	40,43%
5	Graduate	54,86%	71,43%	38,30%

Table 2.5. Percentage of Income with Willingness to Segregate the Waste

Code	Income Category	Overall Precentage	Willing to Segregate	
			Yes	No
1	< 500.000	5,55%	2,60%	8,51%
2	500.000 - 2.000.000	29,48%	14,29%	44,68%
3	2.000.000 - 5.000.000	30,48%	31,17%	29,79%
4	> 5.000.000	34,48%	51,95%	17,02%

Table 2.6. The Data from the Interview in the Landfill Surrounding Area

Question	Closed Landfill Site		Active Landfill Site	
	Yes (%)	No (%)	Yes (%)	No (%)
Suffering from odors?	15	85	95	5
Suffering from operations?	5	95	90	10
Suffering from drainage system?	0	100	10	90
Agree to expand the site?	-	-	60	40

b. SWOT Analysis Result

ASWOT analysis was performed to determine the role of government in the MSW management profile, the condition of the landfill site, and the resident's perceptions and willingness to participate in the MSW management system.

Role of government in the MSW management profile

Regarding the strengths of the role of government in MSW management, the factors observed were:

- A solid waste management system was established.
- The composting effort in the community could be increased.
- Some Non Government Organization (NGO) and community groups were interested in waste management.
- The municipal government established an agreement with the Malang Regency government to implement a regional landfill site.

In terms of weaknesses, the factors observed were:

- The solid waste management service covered 70% of the population.
- Lack of programs to educate the community about waste management.
- Lack of a budget from the government for maintenance of the solid waste management system.
- Lack of facilities and infrastructure to support the system delivering the service.

Regarding the opportunities, the factors observed were:

- Malang Municipality is one of the most rapidly growing cities.
- There are more than five large universities with more than 100,000 students.
- The population is rapidly increasing.
- A waste bank program has been established.
- The Indonesian government rewards the cleanest municipality in Indonesia.
- This municipal government had already approved the spatial and regional planning laws that are based on the solid waste management system.

The factors to be considered as threats for the role of government were:
- Lack of public–private–government partnership.
- Increasing population that needs solid waste management service.
- Future lifestyle changes will change the waste generated.
- An increased habit of using plastic as the number of inhabitants increase.

Strategies derived from the SWOT analysis for the role of the municipal government

While considering the overall strengths, weaknesses, opportunities and threats, the following strategic actions were developed to be used for the effective role of the municipal government:
- Form a collaboration that involves NGOs and community groups to educate the community about waste management.
- Make provisions in the budget for the construction of environmentally friendly facilities and infrastructure to support and maintain the solid waste management system.
- Plan the regional landfill site with the Malang Regency to increase the service coverage of solid waste management using a controlled landfill site or a sanitary landfill site system.
- Present the education program to the community to increase the composting effort to cover the short fall of service coverage of solid waste management.
- Involve students and other young people with the NGOs to serve as active agents to encourage participation in the solid waste management system.
- Encourage and educate inhabitants to become involved in the composting effort and waste bank program.

Condition of the landfill site

The strengths of the landfill were:
- The waste that was dumped in the landfill was decreased.
- The landfill was already managed by an independent authority.
- More than 100 people worked as scavengers at the landfill site.
- A closed landfill site had no effect on the environment and could be used as a public facility.

In terms of weaknesses, the factors identified were:
- The final disposal method of this municipality was the open dumping system.
- Treatment of the leachate in the landfill site was inadequate.
- Supporting equipment, such as bulldozers, excavators and other facilities were

inadequate.
- Almost the entire area of the landfill site was filled with waste.

Regarding the opportunities, the factors identified were:
- Most of the waste was organic material that could be used as compost.
- The methane gas contained in the waste was not treated.
- Some inhabitants living in the area surrounding the active landfill site agreed to expand the area of the landfill site.
- Some workers at the landfill site collected valuable items from scavenging.
- Additional technology could be implemented for treating waste at the landfill site such as an incinerator.

The factors identified as threats for the landfill site were:
- Leachate pollution to the environment.
- Influence of an open dumping operation on the surrounding areas, such as odor.
- Limited available land for expanding the area of the landfill site.
- Resistance from inhabitants to expand the area of the landfill site.

Strategies derived from the SWOT analysis for management of the landfill site
- Develop technology to manage the organic waste that enters the landfill site as compost and capture the methane gas that is produced from the waste.
- Expand the area of the landfill site using an environmentally sound approach and obtain approval from the local community in the surrounding area.
- The authority overseeing the landfill site can collaborate with the scavengers and waste collectors to educate others about recycling waste.
- Proper maintenance of the landfill site to lessen the effect on the surrounding area and environment by using appropriate equipment and facilities, and technology such as membrane covers and insect prevention.
- Construct a proper leachate treatment facility to prevent detrimental effects of the leachate on the environment.
- Use a simple method to predict the leachate quantity and quality that is acceptable for the landfill site in Malang Municipality, accounting for local factors such as the climate, waste characteristics, and landfill operation.

Resident's perceptions and willingness to participate in the MSW management system
The factors identified as strengths of the landfill site were:
- Involvement of housewives to support the solid waste management program.

- The inhabitants were willing to pay money to support waste collection activities in their neighborhood.
- The education level of the inhabitants ranged from medium to high.
- The inhabitants knew that there were several waste items that could be recycled.

In terms of weaknesses, the factors observed were:
- Lack of waste segregation at the source of its generation, e.g., household segregation.
- Inhabitants not cooperating or participating (e.g., Not in My Backyard (NIMBY) syndrome).
- Limited environmental awareness and attitude among the society.
- Lack of information, education and communication resource materials for human resource development.

Regarding the opportunities, the factors observed were:
- Willingness of inhabitants to support waste management could be increased.
- Increase inhabitant’s knowledge of 3R to support management of the system.
- Encourage inhabitants to produce compost and re-use their products.
- Encourage inhabitants to recycle items in their daily life.

The factors considered as threats for the perception of the residents and their willingness to participate in the MSW management system was:
- People generally wait for the government to act.
- Lack of knowledge of 3R.
- Difficulty to change the culture in terms of separating the waste.
- Inhabitant’s awareness was still low even though their knowledge of 3R was sufficient.

Strategies derived from the SWOT analysis of resident's perceptions and their willingness to participate in the MSW management system
- Encourage housewives to separate their household waste.
- Increase the willingness of inhabitants to become involved in the management system, increase the production of compost, re-use products, and use recycled items in everyday life in synergy with the actions of the government.
- Increase the knowledge of 3R through educational approaches based on the inhabitant’s level of education, which was in the middle to upper level.
- Increase inhabitant’s environmental awareness that to maintain their lifestyles, they need to manage their waste and change their culture to separate the waste without

waiting for action from the government.

- Government can encourage inhabitants by distributing information and communicating resource materials to become involved in the waste management system.
- The inhabitants can rise funding that can be used to establish community groups that can become involved in the solid waste management system.

The strategies that resulted from this analysis were focused on the inhabitant's participation and environmental consideration. The strategies for increasing inhabitant participation were related to: educating the inhabitants, increasing the role of students and young people to become involved in the system, increasing the awareness, increasing the effort to recycle and encouraging inhabitants to use recycled materials. These strategies cannot be conducted separately by the community or by the government. There must be collaboration and continuous effort from the community and government to maintain the solid waste management system. The role of the community groups and NGOs could be increased, and the pilot project for managing the waste could be supported by the government.

The strategies for the environmental consideration were focused on proper management of the landfill site. The strategies were concerned with preventing detrimental effects on the environment and the influence of the landfill site operation on the inhabitants in the surrounding area. The strategies were to encourage the landfill authority to change the landfill operation from an open dumping system to a sanitary system and to implement technology to maintain the waste that enters the landfill site. The landfill authority was encouraged to recycle material from the waste and to collaborate with the scavengers and material collectors working at the landfill site. For improved management of the leachate, it is necessary to use a simple method to predict the leachate quantity and quality that is appropriate for the municipal landfill site, taking into account the influence of the climate, waste characteristics, and landfill operation.

The role of government was important for proper implementation of a solid management system in this municipality. The role of the government could be increased by building partnerships and encouraging inhabitants and community groups to change their views on solid waste management systems. These partnerships could be implemented by increasing the government's responsiveness. The government could improve active, comprehensive and appropriate communication between government inhabitants directly, or by using community groups looking for mutual and appropriate consensus between the government and the inhabitants to maintain the system.

2.4 Conclusion

In this investigation, the SWOT analysis focused on the government's role, the landfill management and inhabitant's perception. The strategies from the analysis that were based on the environment and public awareness and that were supported by the government were expected to be applied to improve the performance of solid waste management in Malang Municipality. The strategies can be expanded to other municipalities in Indonesia that have similar problem as this municipality.

The physical aspect of strategies resulting from the SWOT analysis that could be implemented for further research were to use a simple method to predict the leachate quantity and quality that would be appropriate for the municipal landfill site by accounting for local influences such as the climate, waste characteristics, and landfill operation.

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Chapter 3 The Effect of Water Content of Waste Material on Gas Generation

3.1. Introduction

Many cities in developing countries face serious problems in managing solid waste. In Southeast Asia especially, the amount of waste was increases with an increase in the population and urbanization. Several major cities in this area have problems relating to existing landfill sites and inadequate waste treatment. In many places, the leachate is inadequately treated because of a lack of technology and an insufficient budget. In order to predict the environmental effect of leachate on a river and to design an appropriate leachate treatment plant, it is important to determine the quality and quantity of the leachate.

The quality of leachate froma landfill dominated by organic waste is affected by biological degradation. Biodegradation is affected by chemical and physiological factors in the environment, such as the oxygen concentration, temperature, pH, and salinity. One of the most significant environmental factors is the water content. As the water content increases, the activity of the microorganisms generally increases because of better transport conditions for nutrients and an increase in the amount of dissolved substances (Najarno et al., 2004). Moreover, under conditions of low water contents, a lag in the initiation of microbial activity has been consistently demonstrated (Liang et al., 2003).

Under normal conditions, the water content of a landfill site is influenced by local conditions such as climate. However, unlike Japan and the West, Southeast Asia has a rainy and a dry season, where the differences between wet and dry conditions are clearly distinct and affect the extent of biodegradation.

The effect of the water content of the waste on the biodegradation rate has been documented in the literature; the optimum condition for the enzymatic and hydrolytic degradation of high-molecular organic compound materials is above 65% (Rodriguez et al., 2001), and for compostingthebulk material, the value is close to its water holding capacity, which rangesfrom60% to over 80% (Ahn et al., 2008; Zhang et al., 2007; Berriel et al., 2008).

Few researchers have considered the effect of the critical water content on biodegradation of landfill waste. The critical water content is the water content below which biological activity is significantly reduced (Liang et al., 2003; Promier et al.,2009). Biodegradation under extreme changes in the water content, e.g., under tropical climatic conditions, has been examined in some studies, e.g. Visvanathan et al. (1999) and Kawai et al. (2012). Nevertheless, it is still interesting and important to know how the degradation rate of organic material is affected by the various water contents.

The purpose of this study was to examine the effect of the water content on the biodegradation rate duringthe dry season in the Southeast Asian region. An anaerobic batch experiment was conducted to measure gas generation, which is an indicator of biodegradation activity.

3.2. Material and Methods

In this experiment, boiled rice was used to represent carbohydrate, carrot and banana were used to represent cellulose, and meat, chicken meat and fish were used to represent protein. The materials were chosen because of the content of the representative elements in the material (FAO, 2004) and because the experimental material is commonly obtained in Indonesia (Southeast Asian region).The water content of the raw material was 80%, 90%, 60%, 54%, 74%, and 77% for the boiled rice, carrot, banana, meat, chicken meat, and fish, respectively. The raw material was dried using a vacuum drying method to ensure zero water content and to prevent changes in the quality of the materials by oven drying at 105^{o}C. The dried material was properly ground using a blender.

Before being placed in a bottle for a batch experiment, a 25-g substrate was prepared using dry material. The composition of the material in each bottle is shown in Table 3.1. Substrate IV was prepared to compare the results of each material with that of the mixture. The substrate was mixed with distilled water and inocula as shown in Table 3.2. An aerobic digestion liquid from a sewage treatment plant (the Miyazaki Water Treatment Plant) was settled for a day to obtain a supernatant as inocula. The inocula used were in a liquid form and mixed with distilled water to prepare the desired water content. The prepared substrate was placedin a bottle using a spatula.

Table 3.1. The Composition of Material in Each Bottle

Item	Material	Percentage
Substrate I: Carbohydrate	Rice	100%
Substrate II: Cellulose	Carrot	50%
	Banana	50%
Substrate III: Protein	Beef	33.3%
	Chicken Meat	33.3%
	Fish	33.3%
Substrate IV: Mix	Rice	20%
	Carrot	20%
	Banana	20%
	Beef	13.3%
	Chicken Meat	13.3%
	Fish	13.3%

Table 3.2. The Weight of Sample, Water and Inocula in a Bottle

Water Content	Weight of Sample	Weight of Water	Weight of Inocula
30%	25 gr	4.46 gr	6.25 gr
40%	25 gr	10.41 gr	6.25 gr
50%	25 gr	18.75 gr	6.25 gr
60%	25 gr	31.25 gr	6.25 gr
70%	25 gr	52.08 gr	6.25 gr
80%	25 gr	93.75 gr	6.25 gr

A 500-ml plastic bottle was used for the batch experiment. The bottle was close dwith a rubber plug and sealed with glue to prevent gas leakage. The bottle was connected to a gas collection bag through a rubber pipe.

To maintain anaerobic conditions in the bottle, the bottle was purged with nitrogen gas for 3 – 4 minutes. The bottle was storedin an incubator at 30^o C. The temperature was adjusted to simulate average tropical temperature conditions and to show the effect of mesophilic temperatures (25^o– 45^oC) on biodegradation (Chen et.al, 2008).

The gas volume was determined with simple equipment using the vessel-related method. The composition of the gas was determined using gas chromatography with a thermal conductivity detector (TCD Chromatography, model Shimadzu GC-8A, Kyoto, Japan).The carbon and nitrogen content of each material was determined with a C – N Analyzer (C – N Analyzer; model Sumigraph CN – 220 F, Sumika, Osaka, Japan).

A leaching test was conducted on the contents in the bottle after the batch experiment.

The test was performed with Liquid and Solid (LS) ratio 1:10. Each leaching test sample was shaken at 200 rpm for six hours. The sample was centrifuged at 3000 rpm for 10 minutes and filtered with a membrane filter of 0.45 µm.

The sample from the leaching test was determined for pH, Total Organic Carbon (TOC), Chemical Oxygen Demand (COD) and ammonium. The pH was determined with a pH meter apparatus (pH Meter; model HM-30G, TOA-DKK, Tokyo, Japan). The COD was determined by a spectrophotometer colorimetric determination method (Reactor Digestion Method kit; model DREC 2000, HACH, Colorado, USA). The TOC was determined using a combustion-non-dispersive infrared gas analysis method (TOC analyzer: model TOC 5000A TOC Analyzer; Shimadzu, Kyoto, Japan) and the ammonium was determined using a colorimetric method based on the formation of indophenols blue using a spectrophotometer apparatus (Spectrophotometer; model Hitachi U-1800, Tokyo, Japan).

3.3. Result and Discussion

3.3.1. Gas Generation

The accumulation of the gas generated in each substrate is shown in Figure 3.1.Only CO_2 was detected; methane gas was not detected in thesubstrates at any of the water contents. The accumulation of CO_2 increased with time in eachsubstrate. Figure 1 shows that the generation of gas in each substrate occurred early inthe experiment. In substrates I and II, gas generation was observed on day one of the experiment, while in substrate III, the gas was generated on day two. These results corresponded with the result of substrate IV that contained the rice, carrot and banana, which showed gas generation on day one of the experiment. In addition, Figure 3.1 shows that the amount of gas accumulated increased with an increase in the water content.

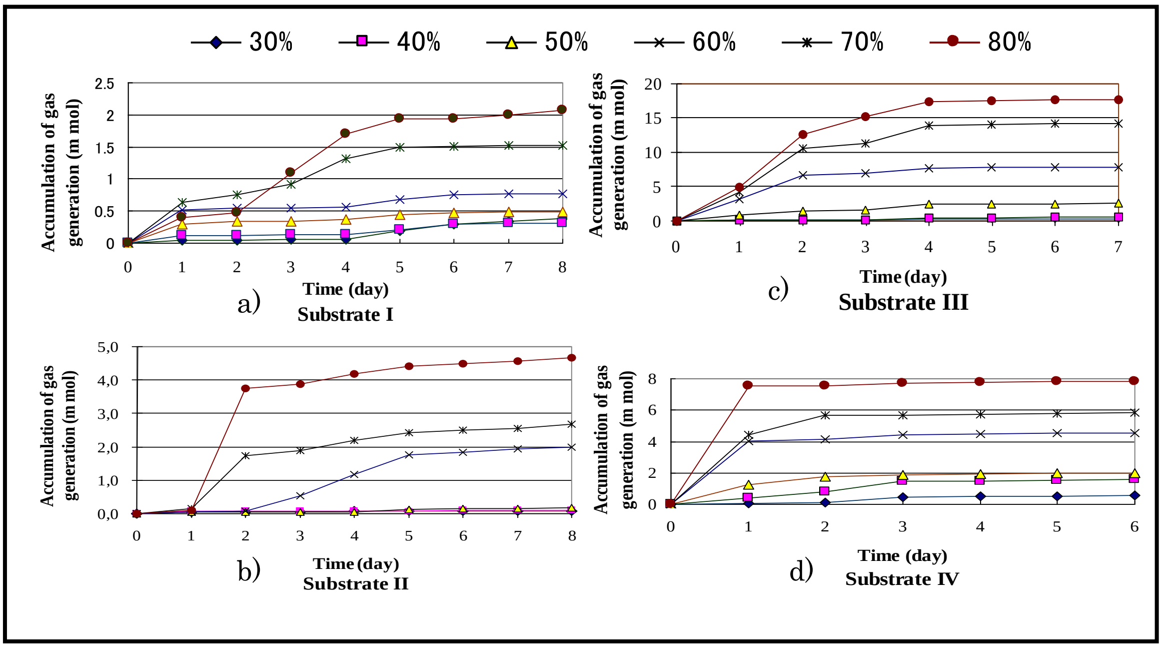

Figure 3.1. Accumulation of Gas Generation with Time

A batch experiment using only inocula (6.25 g/100 g of water) as a blank was conducted and the gas generation was very low. This result indicated that the gas generated from the inocula could be neglected from the determination of the gas generated from the substrate in the batch experiment.

3.3.2. Maximum Gas Generation Rate

As shownin Figure 3.1, the gas generation rate was calculated by subtracting the accumulation of gas generated on a particular day from the gas generated on the previous day. The gas generation rate could also be calculated from the slope of the gas generated on a particular day and the gas generated on the previous day.

Each substrate and water content had their own gas generation rate. The maximum value for each water contents was selected as the Maximum Gas Generation Rate (MGGR). This value was termed the specific MGGR to represent the maximum gas generated for each substrate and water content. The specific MGGR was calculated by dividing the MGGR by the gas generated at a water content of 80%. Abase water content of 80% was selected because the gas generation rate was highest at this water content and therefore showed evidence of the degradation process. Figure 3.2 shows the effect of the water content on the value of the specific MGGR. These values are listed in Table 3.3.

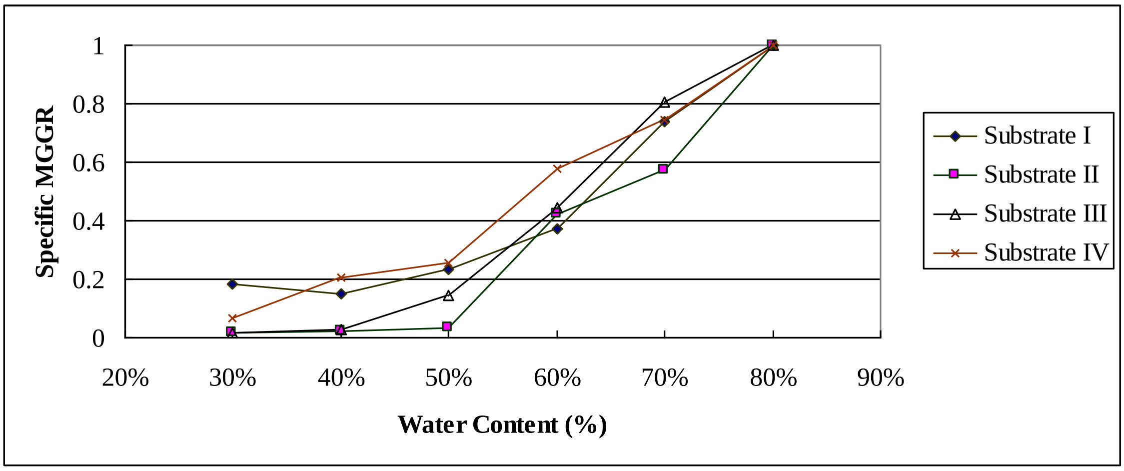

Figure 3.2. Effect of Water Content on Specific MGGR

Table 3.3. The MGGR at 80% (mmol/day)

Material	Substrate I	Substrate II	Substrate III	Substrate IV
MGGR at 80%	0.847	1.826	10.054	3.679

The specific MGGR for each substrate decreased with a decrease in the water content. A similar trend was observed with an increase in the water content of the substrate. Under lower water contents (below 50%), the MGGR was approximately0.2 or lower, but this value increased significantly at water contents higher than 50%. Therefore, for each substrate, a 50% water content was considered as the critical water content where the specific MGGR increased.

A critical water content of 50% was slightly different compared with previously reported work. Liang et.al showed that for microbial activities measured in biosolid blends, a 60–70% range resulted in maximum microbial activity, and 50% was the minimum water content required for microbial activity.The results obtained by Promier et.al indicated that the critical water content for paper and cardboard degradation was higher than 60%.

The critical water content can be used for modeling biodegradation that is affected by the water content, e.g., in a landfill site. At landfill sites, especially in the Southeast Asian region with a tropical climate, the water content of the waste varies and is influenced by the rainfall in each season. In the rainy season, the water content is high, and in the dry season, the water content is low because of different amounts of rainfall. Under such conditions, biodegradation activity varies between the wet and dry season and it was predicted that the biodegradation of the waste in therainy season would be faster than in the dry season.

3.3.3. Effect of the Material in the Substrate

The accumulation of the CO_2 generated was related to the carbon contained in the material. Since every material had different carbon content, it was important to show the accumulation of gas (see Figure 3.3.) The MGGR expressed per unit of carbon of the substrate at a water content of 80% differed between the substrates. Since the substrate materials contained different amounts of carbon, this indicated that the MGGR was influenced by the water content as well as the kind of the material contained in the substrate.

The carbon to nitrogen ratio (C/N ratio) of each substrate is shown in Figure 3.4. The C/N ratio of the substrates varied according to the material contained in the substrate. Substrate I contained a higher C/N ratio compared with the other substrates. The material in substrate IV was a mixture with a C/N ratio higher than substrate III but lower than substrates I and II.

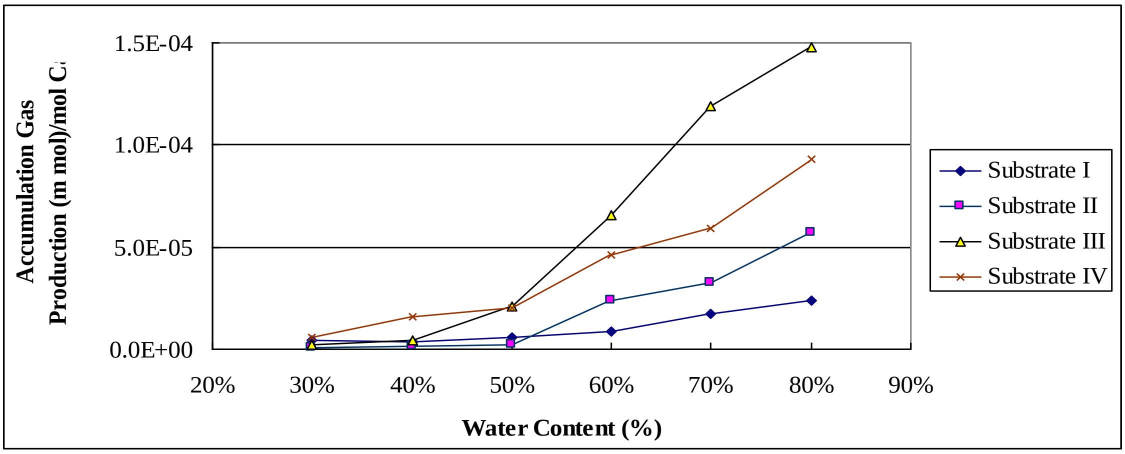

Figure 3.3. Accumulation of CO_2 Generation per Carbon Content of the Substrate

The gas generated from each substrate was related to the C/N ratio of the substrate. Substrate III produced a higher amountof gas compared with the other substrates. In addition, the gas accumulated in substrate IV was lower than substrate III but higher than substrates I and II. This indicated that the MGGR was influenced by the C/N ratio. These result corresponded with other studies where the biodegradation activity was influenced by the C/N ratio (Meenambal et al., 2003; Karnchanawong et al., 2011).

The C/N ratios of the substrates corresponded with the results of Karnchanawong et al.

(2011) and Verma et.al, (2002) in which the optimum C/N ratio varied between 20 and30. The value of the C/N ratio of the substrate could inhibit gas production. A high C/N ratio is an indication of rapid consumption of nitrogen by methanogens and results in lower gas production. A lower C/N ratio, however, causes excessive ammonia accumulation and high pH value, which are toxic to methanogenic bacteria.

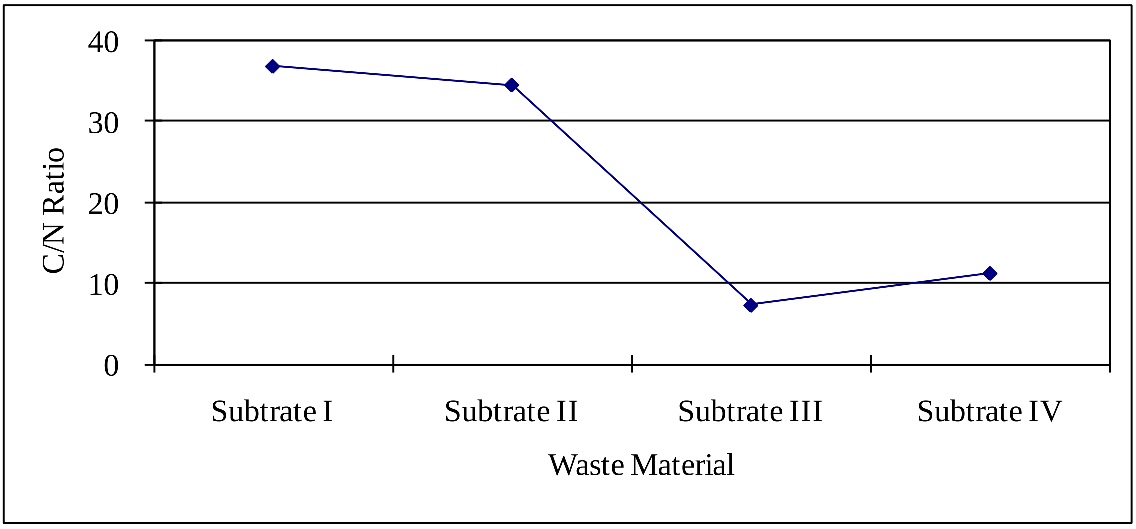

Figure 3.4. C/N Ratio of the Substrate

Figure 3.4 shows that the pH of substrate III was close to neutral. This condition is suitable for generating gas atthe beginning of the degradation process (Nievas et al., 2005; Wolski et al., 2006; Irem et al., 2001). Alternatively, substrates I, II and IV were acidic. These findings corresponded with the MMGR, where the highest value was measured in substrate III compared with the other substrates.

Methane was not generated during the experiment; only carbon dioxide gas was generated. In substrates I, II, and IV, methane was not generated, likely because of the lower pH of the substrate, which inhibited methane production. In spite of the neutral pH of substrate III, methane was not generated. There may another inhibiting factorin the substrate, such as a low C/N ratio. In substrate III, the C/N ratio was approximately8, which was lower than the optimal C/N ratio of methane production, which ranges from 20 – 30 (Verma, 2002).

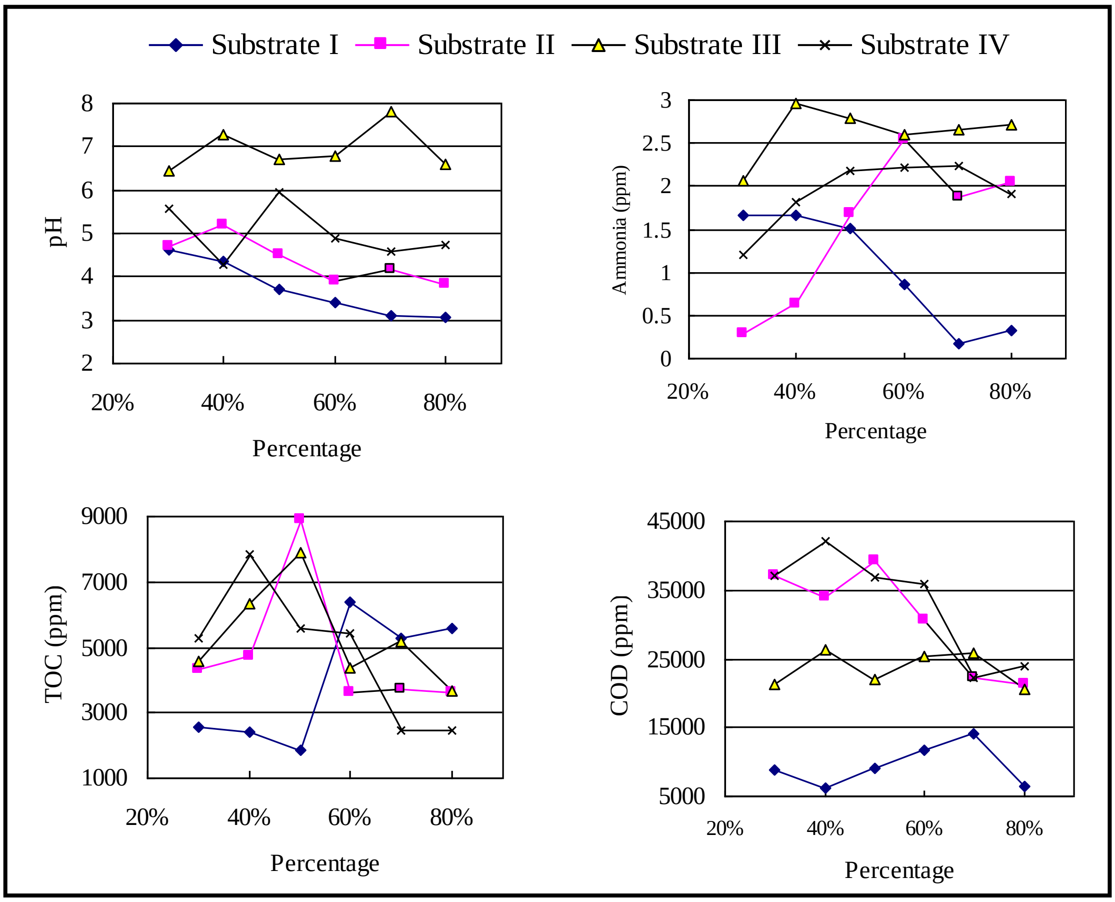

Figure 3.5. pH, Ammonium, TOC and COD in Solution after the Batch Experiment

Figure 3.5shows the values of the pH, ammonium, TOC and COD of the substrates for each water content. As shown in the figure, the COD and TOC values varied between the substrates; however, they were still within the range measured at the start of the degradation process (Wu et al., 2004; Moraes et al., 2005; Renou et al., 2008). This indicated that the degradation process occurred in every substrate in the experiment. The ammonium value was low in each substrate compared with other research (Irem et al., 2001; Pagans et al., 2006; Tatsi et al., 2002). The ammonium value corresponded with the C/N ratio of the substrate material. The higher the C/N ratio in the substrates, show the lower the ammonium value.

3.4. Conclusion

The effect of the water content on the amount of gas generated as an indicator of biodegradation was discussed. The results showed that the MGGR in each substrate increased with an increase in the water content. The critical water content for all substrates was approximately 50%.A different MGGR at a water content of 80% was measured in different substrates. The results showed that the MGGR was influenced by the water content as well as the type of the material in the substrate.

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Chapter 4 Water Content Distribution in a Landfill Site in a Tropical Climate Condition

4. 1. Introduction

Indonesia, as a developing Asian country, faces serious problems in managing solid waste. The waste generated annually increases in proportion to increases in the population and urbanization, and issues related to disposal have become challenging as more land is needed for the final disposal of this solid waste (Idris et al., 2004). Land filling is the most popular method to dispose of the waste. Almost 98% of municipalities and regions in Indonesia have a landfill site as the final disposal site, where only 40% of the landfill sites have a leachate treatment facility (MoE, 2008). This shows that the discharge of leachate without treatment could be a serious problem based on its potential production.

Leachate generation is governed by several factors and processes at the landfill. These factors include the characteristics of the waste (initial composition, particle size, density, etc.), the interaction between the water percolating through the landfill and the waste, the hydrology and climate of the site, the landfill design and operational variables, microbial processes that take place during the stabilization of the waste, and the stage of landfill stabilization (Poulsen et al., 2005; Kuruparan et al., 2003).

One of the influential factors in leachate generation is the field capacity of the waste. This factor depends on the waste characteristics and density as well as the hydraulic conductivity of the landfill. The field capacity will affect the water flow and distribution (Yildiz et al., 2003).

In addition, seasonal variations can significantly affect the nature of waste in the landfill site: in rainy periods, the waste retains much water and is more dense (Tränkler et al., 2001; Mangimbulude et al., 2009). Abundant water in the wet season and evaporation in the dry season would have a large influence on the behavior of the water movement in a landfill site, whichis directly related to the water content of the waste. The evaporation rate will affect the amount of water in the waste.

Moreover, in the literature, relatively few data were found regarding the systematic assessment of landfill leachate in countries with tropical climatic conditions. The water movement behavior in a landfill site under tropical conditions has rarely been investigated, especially in open dumping landfill sites. Some researchers predicted and modeled leachate generation in arid and semi arid regions (e.g., Poulsen et al., 2005; Yaqout et al., 2003; Tatsi et al., 2002), and others examined methane generation in tropical landfills (Machado et al., 2009).

The aim of this chapter was to simplify the methods to predict water distribution in a tropical landfill site and the specified waste. The water movement was represented by the change in the water content of the landfill. The purpose of this research was to estimate the decrease in the water content of a landfill site caused by a tropical climatic condition. A series of columns with different conditions were used in this experiment. The change in the water content of each column was observed and the water content distribution in the column was determined.

4.2. Material and Method

4.2.1 Waste Material

The waste used in this experiment was artificial waste. The composition of the artificial waste was determined with reference to the composition of a sample that was taken from the landfill site in Malang Municipality in Indonesia and analyzed in 2007based on the physical composition waste separation method. The composition of the waste is listed in Table 4.1. The kitchen waste sample consisted of rice, vegetables and fruit. The average water content of the artificial waste was 29.7%. All the material was cut to a diameter less than 5 cm. The sample material that was used is shown in Figure 4.1. The material was mixed manually, and water was added to the mixture to reach the initial water content of the waste. The initial water content was 66 - 70%, which simulated the waste at the beginning of the dry season. The material and water were mixed before being packed into a column.

Table 4.1. Composition of Artificial Waste

No	Type of Materials	Weight Percentage
1	Kitchen waste	45.53%
2	Plastic	30.01%
3	Paper	12.76%
4	Clothes	11.70%

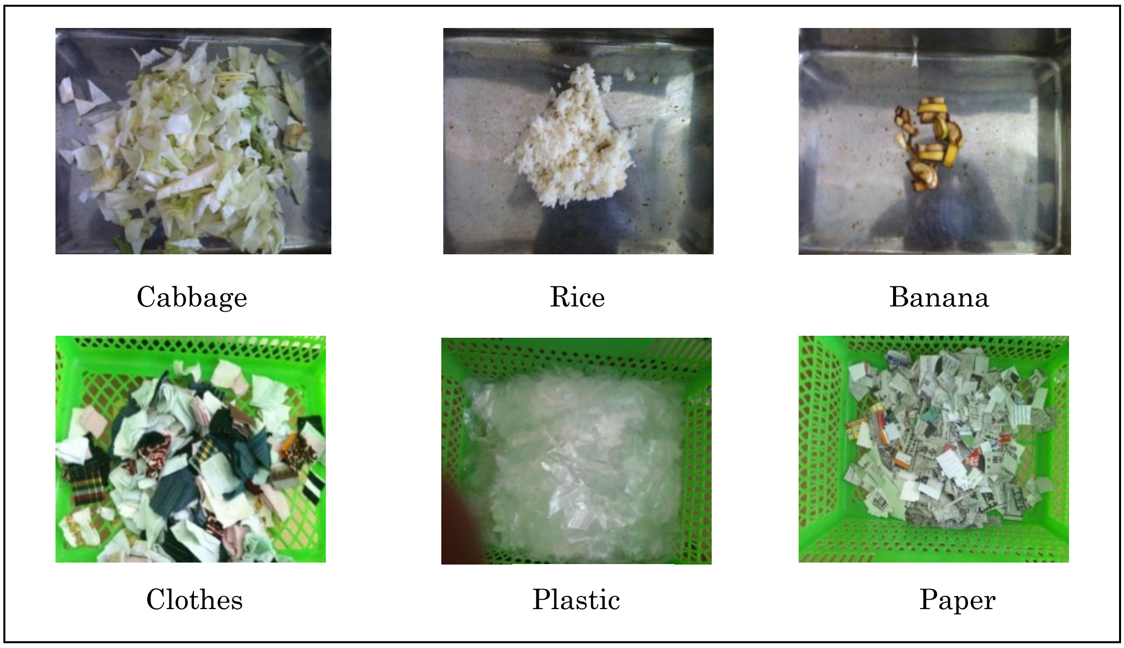

Figure 4.1.Photograph of Artificial Material Sample

4.2.2 Column Apparatus and Sample Preparation

The column apparatus used in this experiment was PVC pipe with a 10-cm diameter. The height of the entire column was 2 m. To drain the water at the bottom of the column,every column was equipped with a tube on the side of the column at the bottom. A permeable sponge with a height of 10 cm was installed inside the bottom of the column to prevent the water from clogging in the draining process.

Three series of column were used to investigate the time sequence of the water content. The time periods for the experiments were one month, two months and four months. Each series of columns were used to investigate three conditions of the sample; low-density waste (L), high-density waste (H) and high-density waste with a soil cover (C). The density of the sample was based on field research of Indonesian waste that was collected from the landfill site in Malang Municipality. The density of the low-density waste was 457 kg/m^3 and the density of the high-density waste was 661kg/m^3.

The density of the packed waste was reached by compactingthe desired weight of the waste into 25-cm layers using a simple manual compacting device. The columnwas filled layer by layer until the heightof the waste in the column reached 1.5 m. Sand was used as a cover for column C and was compacted at the top of the layer with a thickness of 20 cm usingthe same method used for the waste compaction.

The columns were placed in a chamber covered with Styrofoam to prevent the influence of the outside temperature. The temperature inside the chamber was maintained at 30^{o}C using three sets of heaters as shown in Figure 4.2. The temperature was recorded every day. The excess water that drained from the column was recorded. After the time sequence was finished, the column was cut every 25 cm. Every piece of the sample that was cut was dried in an oven at 60^{0}C to determine the water content of the waste.

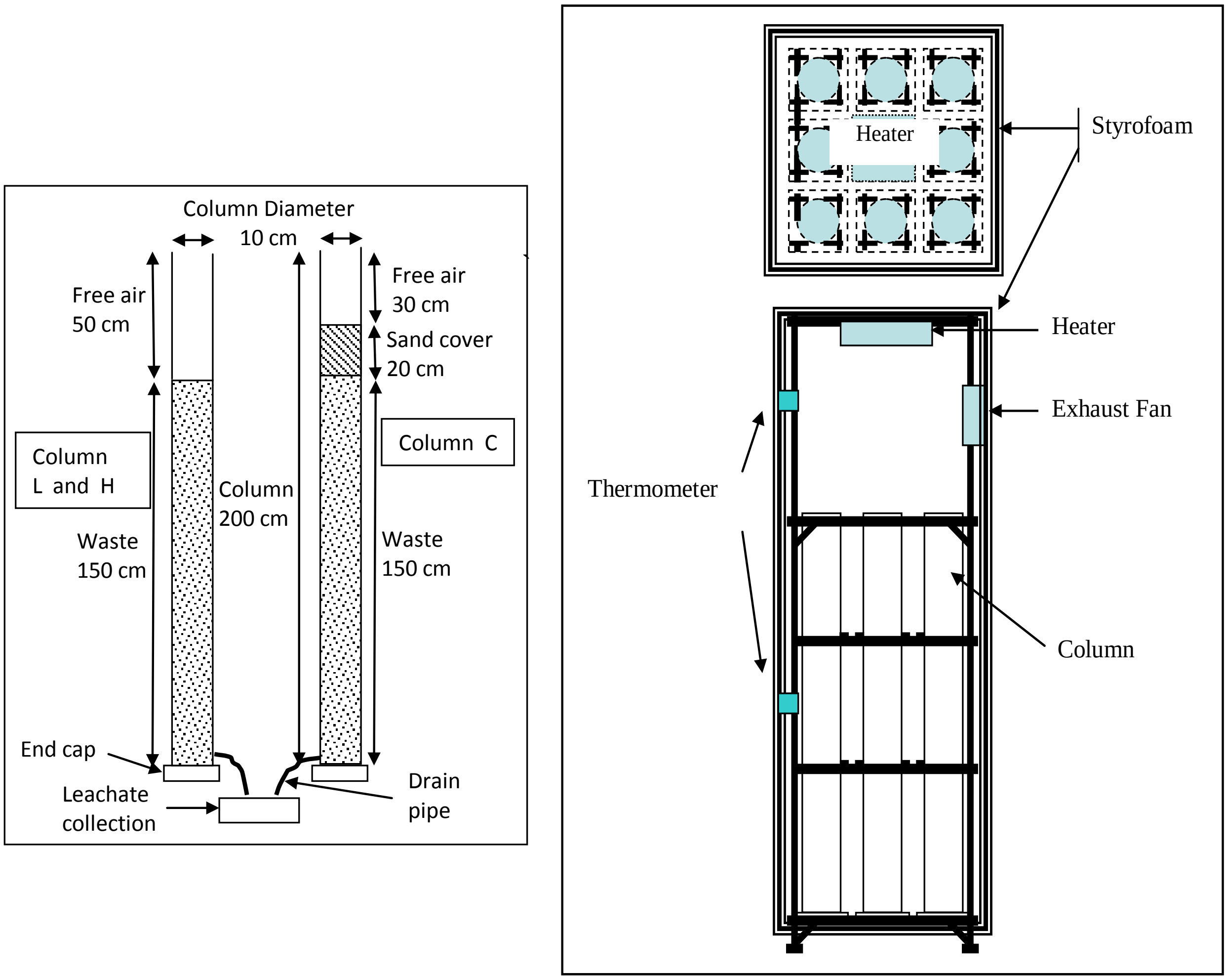

Figure 4.2. Illustration of the Column and Placement of Columns in Chamber

4.2.3 Field Research

The field sampling was conducted by collecting boring samples in the middle of the dry season (July2011) from the Supit Urang landfill site in Malang Municipality. Seven bore pits (SU 1 – SU 7) were bored to a depth of 3 m. In Table 4.2, which shows the conditions of the bore pits used in the field survey, SU 1 and SU 2 represent a dumping site with a cover soil. Bore pits SU3, SU4 and SU 5 represent a dumping site without a cover soil, and SU 6 and SU 7 represent old dumping site with a cover soil. The water content of the samples was determined with the drying in oven with 60^0 C.

Table 4.2. Condition of Bore Pits at the Field Survey

No	Bore pits	Waste condition
1	SU 1	Waste with cover soil, young dumping site
2	SU 2	Waste with cover soil, young dumping site
3	SU 3	Waste without cover soil, relative new waste
4	SU 4	Waste without cover soil, new waste
5	SU 5	Waste without cover soil, new waste
6	SU 6	Waste with cover soil, aged dumping site
7	SU 7	Waste with cover soil, aged dumping site

4.3. RESULT AND DISCUSSION

4.3.1 Water Content Distribution in a Column

4.3.1.1 Column L Water Content Distribution

The water content distribution (WCD) in column L at each time sequence is shown in Figure 4.3.

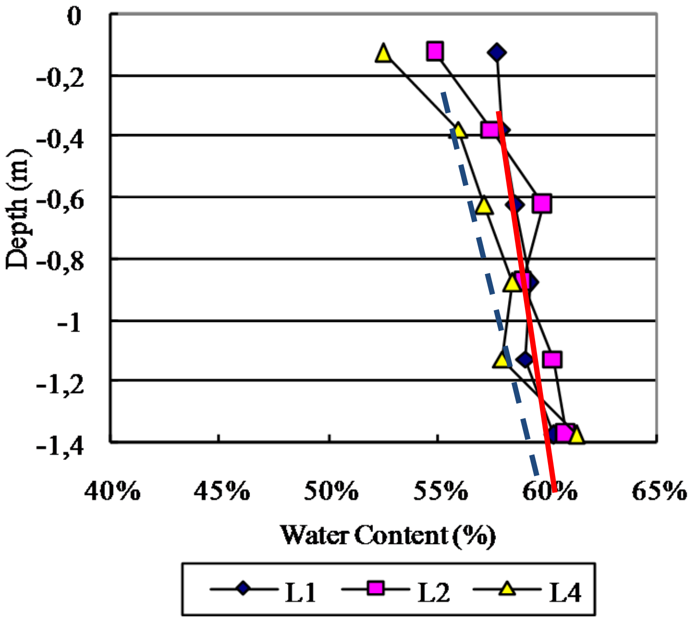

Figure 4.3.Water Content Distribution in L Column

For column L, after the first month of the time sequence (L1), the water content ranged from 58% to 61%. The water content was distributed across the slope line (the solid line in Figure 4.3). The slope line indicated the water movement, which showed that the decrease in the water content was the same in each layer. The water content distribution was caused by water movement from the upper layer to deeper layers. Water from the upper layer would move to deeper layers, and would drain out the column from the deepest layer.

In two month sequent (L2), the water content distribution was forming the same slope line as L1. In the top layer, the water content was 3% lower than that in the one month time sequence. According to slope line, the water content in the top layer was not only influence by the water movement, but also influence by the evaporation. Because the water content decrease was lower than the water content that the slope line resulted. The result of L column in two sequence shows that the evaporation influence was occurred and only occurred in the top layer of column. While in the deeper layer, water content was influenced by the water movement in the column.

In the four-month sequence, the water distribution formed a slope line (dotted line), but the slope was steeper than in the one- and two-month sequences. The steeper slope line indicated that the water movement in the column continued in deeper layers in this time sequence and the water content decreased compared with the two-month sequence. As shown in Figure 4.3, the water content in the top layer was low and did not form a slope line, which indicated that evaporation occurred in this time sequence.

The column L results showed that evaporation was significant overtime. The water content distribution in the one- and two-month sequences was similar, showing that evaporation affected the water content in the top layer after two months.

4.3.1.2 Column H Water Content Distribution

The water distribution for column H for each time sequence is shown in Figure 4.4. For the one-month sequence, the water content ranged from 57% to 60%. The water content distribution was not observed in this sequence because no slope line was formed, which indicated that the water content was decreased by water movement or evaporation.This water content distribution could be caused by the compaction of the waste. High compaction, where the pore density between waste particles is small, prevents water from entering the waste and infiltrating deeper layers by the force of gravity. The time it takes for water to flow through high compaction waste is longer than in low compaction waste.

In the two-month sequence, the water content distribution formed a slope line, except in the top layer of the column.The slope line indicated that the water movement from the upper to lower layers continued in this sequence. Evaporation occurred in the top layer of the column because the water content in the top layer did not form aslope line, whereas the water content in the deeper layers did

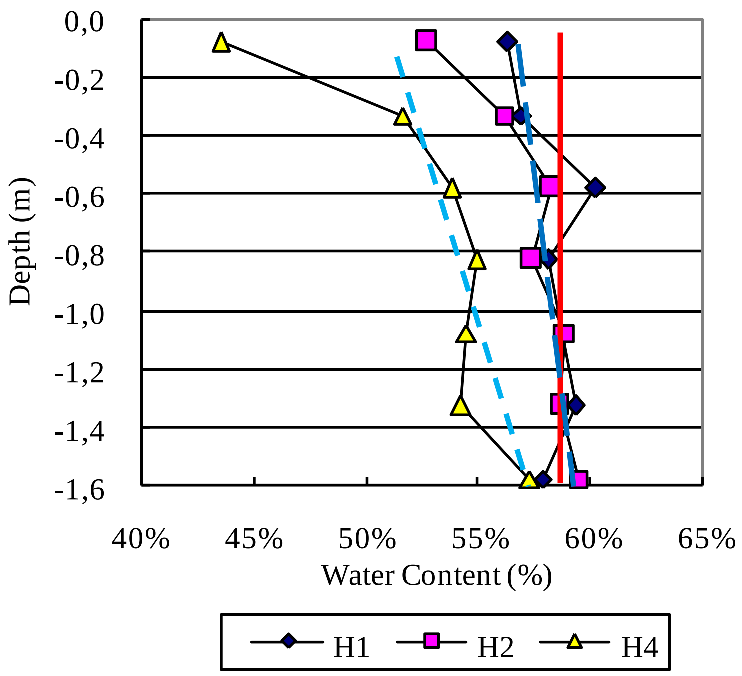

Figure 4.4.Water Content Distribution in H Column

For the four-month sequence, the water content distribution formed a slope line except in the top layer of the column.The water content was lower than in the two-month sequence.This result showed that the water content distribution was influenced by the water movement because the decrease in the water content was basically the same in the deeper layers and formed a slope line (dotted line). In the top layer of the column, the water content was lower than in the two-month column and did not form aslope line. This water content decrease indicated that evaporation occurred in the top layer.

The results for column H for the four-month sequence shows that the water content decreased more than in column L. Thisis because high-density compaction results in small pores between waste particles, and water cannot be retained. The ability to keep water in the pores is termed field capacity. The high compaction waste column had a lower field capacity than the low compaction waste column.

The results of column H indicated that the high compaction of the waste resulted in slow water movement in the waste.Evaporation occured in the top layer of column

H.Compaction might influence the field capacity of the waste. Results of a comparison between columns L and H indicated that evaporation only occurred in the top layer of the waste and it depended on the time, and the water movement influenced the water content distribution in deeper layers. The high-density waste had a lower field capacity than the low-density waste. Therefore, in column H, the water content was lower than column L because the ability to keep water in the pores in column H was low. The field capacity results correlated with the results from the preliminary field capacity experiment using the same samples. The field capacity of the high-density waste was approximately 55% and was 58% for the low-density waste.

4. 3.1.3 Column C Water Content Distribution

The water distribution of column C is shown in Figure 4.5. In the one-month sequence, the water content ranged from 52% to 58%. The water content distribution was not observed in this sequence; no slope line was formed that indicated the water content was decreased by water movement or evaporation. The water content distribution was almost the same as column H except that the water content of the top layer of the column was lower. The lower water content might result from the sand that was used as a cover, which absorbed water from the waste because of the capillarity action of sand.

In the two-month sequence, the distribution of the water content formed a slope line. Only in the top layer was the water contentlow. The water movement influenced the water content distribution in this time sequence, shown by the formation of the slope line (dotted line). In the top layer, the water content decreased because water absorption by the sand continued.

The slope line of the water content in the four-month sequence was steeper than the two-month sequence. This indicated that the decrease in the water content continued. The water content distribution in the top layer was similar to that in the two-month sequence. Distribution of the water content in this sequence was similar to the distribution in column H except the water content in the top layer was different. The compaction incolumns H and C was the same and resulted inthe same water content distribution.

From Figures 4.4 and 4.5, the water content distribution in the deeper layers is the same for conditions with or without a cover soil. At the bottom of the column, the water content was almost the same for each condition. This was caused by the water that was still retained in the waste flowing from the upper layer. The other reason is that some water was retained and stored in the permeable sponge at the bottom of the column, which influenced the water content at the bottom of the column. The water content at the bottom of the column corresponded with the field capacity of the waste reported by other researchers (Vaidya, 2002; Wong, 2009; Yuen et al., 2001) and the results of the field capacity from the preliminary experiment.

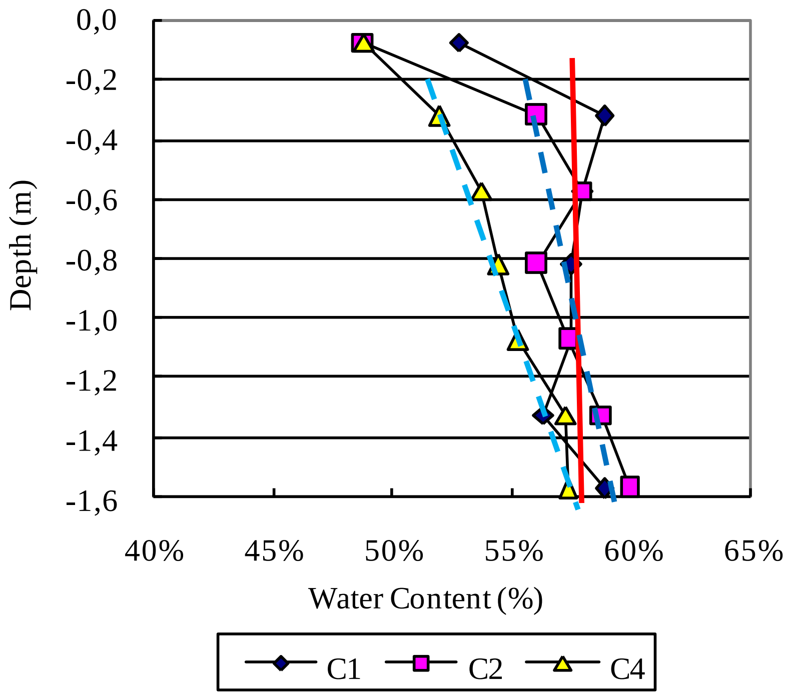

Figure 4.5.Water Content Distribution in C Column

4.3.2 Evaporation

The water balance of each column is shown in Table 4.3. The water balance was calculated by subtracting the initial amount of water at the beginning of experiment from the sum of the final amount of water at the end of experiment, the drained water and the water remaining at the bottom of column.

Table 4.3. The Water Balance in Column

	L1	H1	C1	L2	H2	C2	L4	H4	C4
Total initial water (gram)	5,967	8,426	8,480	6,032	8,555	8,478	6,124	8,662	8,733
Total final water weight (gram)	4,186	6,117	5,968	4,061	5,888	5,850	3,729	5,014	5,004
Total drained water (ml)	779	949	1,139	916	1,174	1,246	1,005	1,485	1,574
Total remaining water (ml)	100	105	165	105	120	100	100	155	150
Total evaporation (ml)	902	1,256	1,208	950	1,373	1,283	1,290	2,009	2,005
Evaporation rate (mm/day)	3.8	5.3	2.4	2.0	2.9	1.3	1.4	2.1	0.9
Water loss ratio	15.1%	14.9%	14.2%	15.7%	16.0%	15.1%	21.1%	23.2%	23.0%

The result showed that the water drained from the columns increased with time. The columns with high compaction (H and C) had more drained water than the low compaction waste (L). However, the water loss ratio, i.e., the ratio of the water lost from the column to the initial amount of water in the waste was similar for each time sequence. This was caused by the volume of water contained in the waste in each column, where the volume of water in columns H and C was higher than in column L.

The results from columns H and C showed that total evaporation was similar for each time sequence. However, as shown in Figure 4.6, the evaporation rate was different. The evaporation rate of column H was higher than column C because the sand used as a cover soil absorbed water from the waste through capillary action and water was retained in the sand. The evaporation rate showed the influence of the cover soil. The cover soil prevented water from evaporating to the air.

The results from columns C and H showed that the amount of drained water in column C was higher than column H even though the density of both columns was the same. This result is probably because of the different pressures that occurred due to the sand cover in the top layer of the waste. The water could not evaporate from the top layer of the waste and drained to the bottom of the column by gravitational force, whereas in column H, the water flowed to the bottom of the column or evaporated from the top layer of the waste, which was not covered.

Evaporation was not measured every day; it was only estimated at the end of the time sequences. The volume of evaporated water from column L was lower than column H The decrease in the evaporated water was gradual. The decrease indicated that the daily evaporation from columns L and H decreased with the time sequence and depended on the compaction of the waste. The low compaction waste contained a lower amount of water than the high compaction waste. The lower amount of water resulted in a low evaporation rate. Even though column L had a larger waste pore volume than the high compaction H column, the amount of water contained in the waste influenced the evaporation. The flux of evaporated water decreased over time because the amount of water for evaporation became lower. The evaporation rate result indicated that the volume of evaporated water in the waste was influenced by the compaction with respect to the amount of water contained in the waste and its decrease over time.

Using Blaney Cridley method (Allen et al., 1986) a 5.5 mm daily evaporation rate was obtained. This evaporation rate was similar to the one-month sequence in column H, but higher than columns L and C. In the two- and four-month sequences, the experimental results were lower than the calculated value. The different evaporation rates might be caused by the amount of water in the waste. Column H contained more water than column L, while more water was retained by the sand cover in column C.

The experimental result of the evaporation rate from the column correlated with the result of an evaporation test using the Direct Evaporation from Waste Body (DEW) test (Abdoli et al., 2009), which showed that the evaporation from the free surface waste was less than 6 mm per day. As shown in Figure 4.6, the result from the column indicated that the evaporation from the waste differed from the free water surface or soil and had a lower value. Only for the short time period was the result similar because the water content was high at the beginning of the experiment. The water content decrease over the time resulted in a lower amount of water for evaporation

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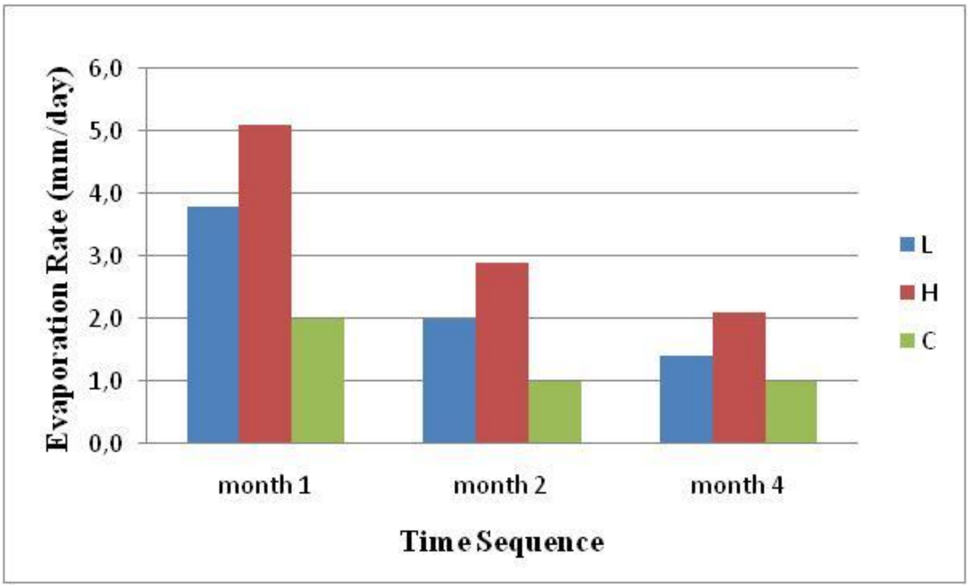

Figure 4.6.Evaporation Rate in Column

4.3.3 Field Survey

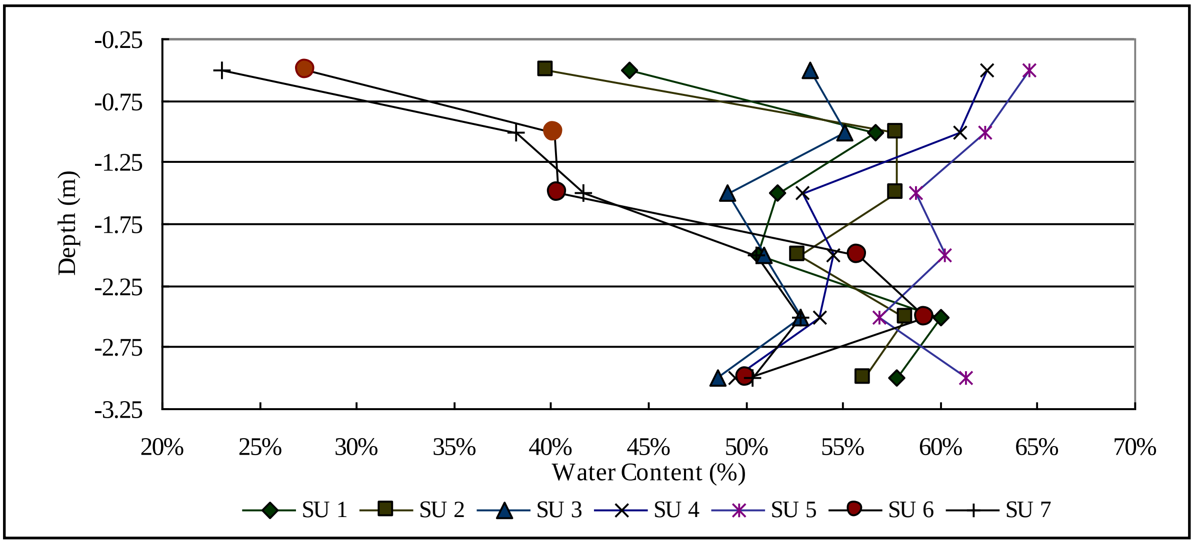

Figure 4.7 Water Content from Field Boring

Figure 4.7 shows the water content results from field boring. For bore holes in the new waste (SU 4 and SU 5), the water content in the top layer was high. The high water content was caused by the new waste dumped in that area that had high water contents. The water content in the lower layer was lower than the top layer. The low water content might be because the water content of the waste was influenced by evaporation before the new waste was dumped and became the upper layer. In SU 3, the waste did not have a cover layer, but the waste dump was older than SU 4 and SU 5 and the water content in the top layer was low. The low water content might be because of evaporation that occurred. In the lower layer of SU 3, the water content was similar to that in SU 4 and SU 5. The water content varied between 50% - 60%, which corresponded with the field capacity of the waste (Vaidya 2002; Wong, 2009; Yuen et al., 2001).

The field result of SU 3 corresponded with the results from columns H and L, where the water content in the upper layer was lower than in the lower layer and the water content of the lower layer corresponded with the field capacity. The water content distribution was not observed in the field results of SU 3, SU 4 and SU 5, which might be caused by the time the field research was conducted. This research was conducted in the middle of the dry season (July 2011), after more than one month with no rainfall. The field result corresponded with the conditions in the first month of the column experiment where the water distribution was not observed in column H.

Figure 4.7 shows that the bore holes with a cover soil (SU 1, SU 2, SU 6 and SU 7) had similar water content distributions among them, i.e., low in the top layer of the landfill and increasing with increase in depth. The water content distribution was caused by the influence of the cover layer. The water content in the top layer in SU 6 and SU 7 was lower than SU 1and SU 2. This might be caused by the age of the waste, which was older in SU 6 and SU 7 than SU 1 and SU 2.

The water content at a depth greater than 1 m that occurred in the field ranged from 50% to 60%, which corresponded with the results of the column experiment for every condition. The results corresponded with results from Yuen et al. (2001), who showed that the water content of the waste in the landfill site varied from 30% to 60% from the surface to a depth of 3 m.

4.4 Conclusion

The water content distribution in a landfill was discussed with reference to a column experiment. Results from the water content distribution in columns L, H and C indicatedthat the evaporation from the waste only occurred in the top layer of the waste and it depended on the time period, whereas the water content distribution in deeper layers was influenced by the water movement.

The compaction of the waste influenced the field capacity of the waste. The high-density waste had a lower field capacity than the low-density waste.The cover soil only influenced the water content distribution in the top layer of the waste. The water content distribution at the end of the experiment corresponded with the field capacity of the waste material and the field conditions of the landfill site.

4.5 References

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Chapter 5 Prediction of Leachate Quantity and Quality Generation

5.1 Introduction

Leachate in landfills is considered to be a factor of environmental risk and represents a key consideration during the design and operation of a landfill. The factors affecting the chemical composition and the production rate of leachate include the characteristics of the waste (initial composition, particle size, density and so on). The other factors are interaction between the percolating landfill moisture, the hydrology and climate of the site, the landfill design and the operational variables, and microbial processes. The entire factors are taken place during the stabilization of the waste, and the stage of the landfill stabilization.

It is widely accepted that moisture content is important in controlling the decomposition of waste within landfill sites, and that the rate of decomposition generally reduces with reduction in moisture content. Moisture content affects landfill decomposition through a variety of different ways. Water is the medium through which biochemical reactions take place, including the microbiological decomposition of refuse. The processes of hydrolysis, hydration and solubilization promote the decomposition of waste by water (Yildiz et. al, 2004).

In the case of landfill process modeling, the significance of local factors such as the waste composition, disposal method and protection systems against potential impacts, the heterogeneity of the medium, as well as the several physical and biochemical phenomena that need to be considered (e.g., climatic conditions, liquid and gas movement, biological and chemical degradation of the waste, age of materials), makes the development of models applicable to different landfill facilities.

Several computer programmers for estimate leachate generation have been developed, for example: HELP (U.S. EPA 1984), FULLFILL (Noble 1991), and SOILINER (Johnson 1986). All of them are based on the so-called Water Balance Method (WBM) developed by the U.S. Environment Protection Agency. (Teresa et. al, 2003; Schneider et. al, 2005)

Because limited information exists in the literature on models of the interaction between tropical climates and leachate prediction, it is necessary to predict leachate generation for landfills using climatic condition in Indonesia with a simple and daily leachate prediction method.

The aim of this chapter was to develop a model to predict leachate quantity and quality of the landfill, and to evaluate the effects of a cover soil on the leachate generation pattern and the effect of the beginning of the landfill operation time on the leachate generation pattern. The combination of a water balance and degradation model in this paper was carried out for a tropical condition and an open dumping landfill site from the beginning of the waste disposal. The influence of the water content, depth of evaporation, field capacity, design and operation of a landfill that were appropriate for a tropical climate and landfill conditions was considered for use in the model.

Since daily data of leachate quantity and quality generation is limited, it was difficult to verify the results of the model. The verification of the model was conducted by comparing the trends resulting from models from other research in appropriate areas.

5.2 Material and Method

The combination of a water balance and degradation model was used as an appropriate method to predict the leachate quantity and quality generated from the landfill site. This model was applied to the Supit Urang Landfill site in Malang Municipality, Indonesia. This model was used with assumptions and approaches that considered the landfill conditions and climate of a tropical area.

5.2.1 Assumptions of the Leachate Quantity Model

The water balance, used as the model to predict leachate generation, makes calculations regarding the landfill operating data and the behavior of the leachate inside a landfill. As a general assumption of the water balance model, confining cells are placed in layers, with each cell being constructed above the cells in the layer below. Thus, the leachate produced in an upper cell infiltrates down proportionally to the underlying area. The leachate flow is related to the field capacity of the waste. After the field capacity requirementis fulfilled, the water that enters the waste percolates as leachate. The other assumption in this method is that the leachate only flows down vertically, andhorizontal flow between cells in the same layer is not considered relevant for the calculations.

An additional assumption of this method for this study was the application of the climatic conditions. Rainfall was estimated using the average rainfall area method for one day. The rainfall data from a rainfall station near the landfill from 2008 to 2010 was used. The evaporation was calculated with the Blaney-Criddle equation, and runoff was calculated with the rational method (Sammis et al., 2011; Allen et al., 1986). The run off value depends on the cover or waste material and the rainfall intensity. Evaporation only occurred in the top of the waste layer, approximately 0.5 m from the top of the layer. The calculation of evaporation was only conducted in the top layer of waste because in the cell beneath the top layer, evaporation did not occur, as mentioned in Chapter 4 of this thesis. The waste water content was calculated on a wet basis by comparing the weight of the water in the waste to the total weight of the waste.

The water balance method calculated the interaction between the rainfall, evaporation, and runoff as a simultaneous calculation. The infiltration, water storage in the waste (waste water content), field capacity, and percolation were the result of the simultaneous calculation that was used as the basis to predict leachate quantity. The sequence of the water balance method used in this study is described in Figure 5.1.

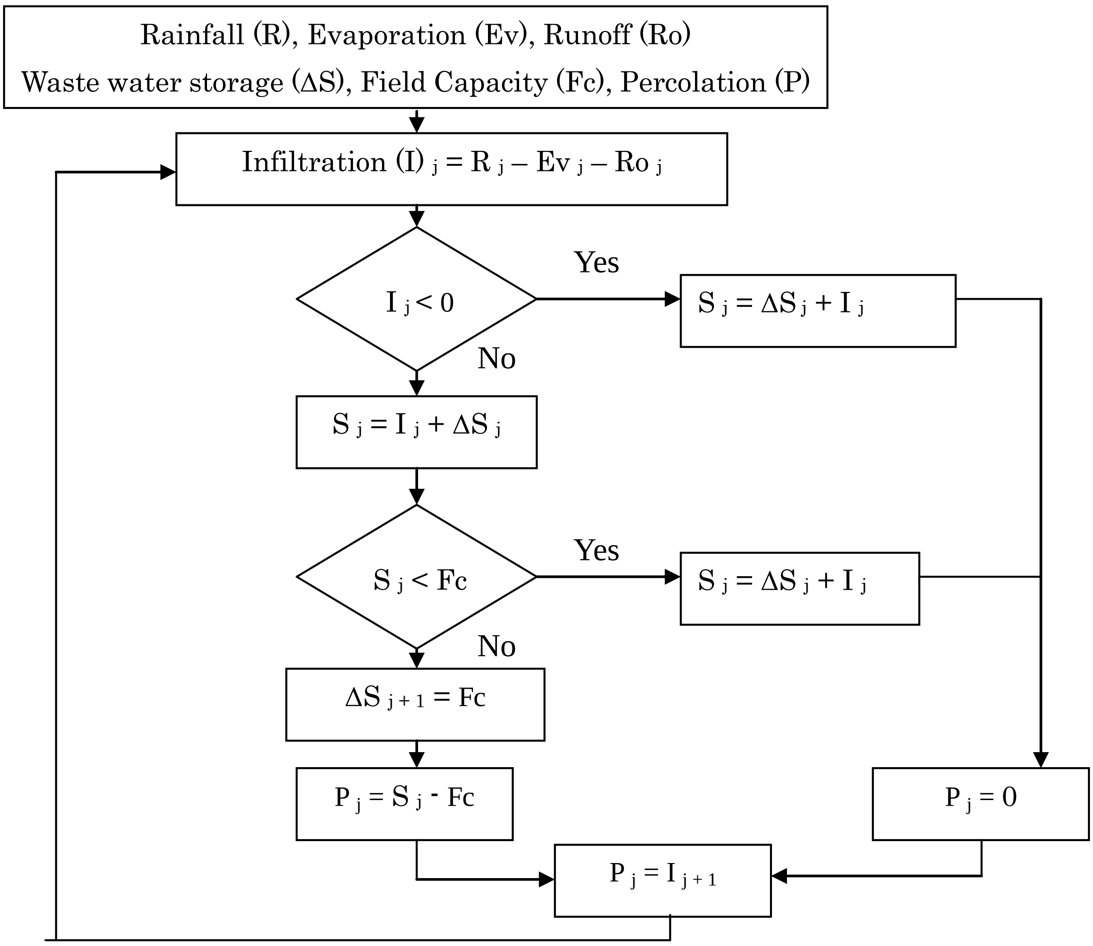

Figure 5.1. Flowchart of Water Balance Model

Where:

ΔS_j = waste water storage (initial waste water content) in t_j (%)

Ev_j = evaporation from the waste surface in t_j (mm/day)
R_j = rainfall on the waste in t_j (mm/day)
Ro_j = runoff flow from the surface of waste in t_j (mm/day)
I_j = infiltration in t_j (mm/day)
Fc = field capacity of waste (%)
P_j = percolation, the result of leachate flow at the bottom of landfill in t_j (mm)
= infiltration in t_{j+1}
S_j = the storage change in the waste due to the process of the water flow in t_j (%)

5.2.2 Assumption of the BOD degradation in the waste

The BOD biodegradation model that predicts the leachate quality uses the assumptions of the dissolution and degradation model bydeveloping relationships based on the first-order rate equation. The process of biodegradation in the cells of the landfill is illustrated in Figure 5.2 as follows:

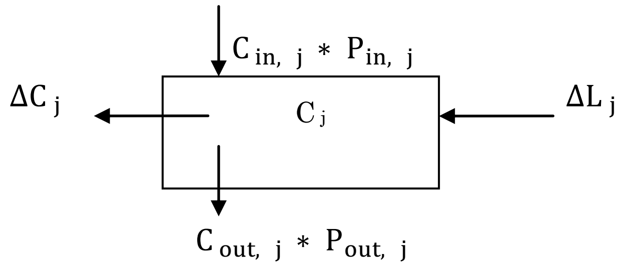

Figure 5.2. Illustration of the Biodegradation Process in Cell of Landfill

Where:
C_j = the concentration in the cell at time t_j (mg/l)
$C_{in,j}$ = the concentration that enter the cell from the cell above at t_j (mg/l)
$C_{out,j}$ = the concentration that leaves the cell and enters the cell below at t_j (mg/l)
$P_{in,j}$ = the discharge that infiltrates the cell from the cell above at t_j (l)
$P_{out,j}$ = the discharge that leaves the cell and enters the cell below at t_j (l)

The ΔL_j and ΔC_j are the dissolution and degradation of BOD in material amount that occurred in the cell at t_j. The Dissolution of BOD in the cell was calculated as follow:

$$L = L_0 * e^{-k_L t} \qquad (1)$$

Where:
L = initial weight of the BOD contained in the waste (kg – BOD / kg – waste)
L_0 = weight of the BOD contained in the waste after process dissolution occur (kg – BOD / kg – waste)

$$L_j = L_{j-1} - L_j = L_{j-1} * (1 - e^{-k_L \Delta t}) \quad (2)$$

where:

ΔL_j = weight of dissoluble material in the cell for Δt (= $t_j - t_{j-1}$) (kg – BOD / kg – waste)

k_L = dissolution rate of the waste (1/day)

And the degradation process was calculated as follow:

$$C = C_0 * e^{-k_C t} \quad (3)$$

Where:

C = initial concentration in the cell (mg/l)

C_0 = concentration in the waste after process degradation occur (mg/l)

$$C_j = C_{j-1} - C_j = C_{j-1} * (1 - e^{-k_C \Delta t}) \quad (4)$$

Where:

ΔC_j = degradation concentration in the cell for Δt (= $t_j - t_{j-1}$) (mg/l)

k_C = degradation rate of the waste (1/day)

The calculation of the concentration in the cell the day after j day was calculated using the mass balance equation as follows:

$$\frac{C_{j+1} - C_j}{\Delta t} = \frac{(C_{in\,j} * P_{in\,j})}{v_j} - \frac{(C_{out\,j} * P_{out\,j})}{v_j} + \frac{\Delta L_j * w}{v_j * \Delta t} - \frac{\Delta C_j}{\Delta t} \quad (5)$$

Where:

C_{j+1} = the concentration in the cell at time j+1

v_j = the volume in the cell at time j (l)

Since the critical water content, water content where the degradation start to occur, was defined as 50%, the calculation of the equation (5) becomes:

$$\frac{C_{j+1} - C_j}{\Delta t} = \frac{(C_{in\,j} * P_{in\,j})}{v_j} - \frac{(C_{out\,j} * P_{out\,j})}{v_j} + \frac{\Delta L_j * w}{v_j * \Delta t} \quad (6)$$

At these conditions, the degradation process was terminated. And if the water in the cell become zero ($v_j = 0$), the concentration in the cell did not changed, $C_{j+1} = C_j$.

In this research, for calculation of degradation the dissolution and degradation rate was determine using k_L = 0,00375 /day and k_C = 0,01/day (Lee at.al, 2001). And the initial weight of contain BOD in the waste was determined using L = 1000 mg BOD /kg waste. (Damanhuri et.al,2005).

5.2.3 Application the model to the landfill site

Some assumptions had to be made regarding the Supit Urang landfill, as the water balance method was being applied to a real case of an existing landfill. It was necessary to make these assumptions because much of the data about the operation of the landfill were not accurate, for example, the width area of cells and the daily disposal rates were only average values of diverse data. Assumptions were also made that the density, waste water content and field capacity of solid waste did not change throughout the year.

Some assumptions that used in the prediction model were:

- The waste dumped in the landfill was 1,000 m^3 per day
- The cell area was 8,000 m^2
- The mass of the waste occupied 80% of raw mass volume caused by the compaction activity
- The waste will be dumped at height of 1 meter every layer, and the final height of the waste is 10 meters (10 layers).
- The other assumption made was to exclude the influence of consolidation of the landfill on the variation of the field capacity of the waste, because only information on the field capacity of fresh solid waste was available and could be referred to. The field capacity of the waste was determined as 50% of the water content (Jang et al., 2001).
- The runoff coefficient for the cover soil was determined as 0.7, the runoff coefficient for the waste was specified as 0.3 (MoE, 2001), and the hydraulic conductivity ranged from $2.8 * 10^{-3}$ to $11.8 * 10^{-3}$ (Reddy et al., 2009).

In the model calculation, three cover soil conditions were considered to evaluate the influence of a cover soil on the leachate quality and quantity in the landfill. In case 1, the landfill did not have a cover soil; this is called open dumping, which is the usual method in Indonesia and developing countries. Case 2 was the application of a cover soil on top of the waste layer, which was implemented 10 days after the waste, was first dumped. Case 3 was an intermediate cover soil; soil was applied in the middle of the waste dumping, implemented five days after the first layer of waste was dumped. In case 3, the cover soil was also implemented on top of the waste layer. The illustration of the waste layers for every case is shown in Figure 5.3 to Figure 5.6.

Four case simulations for the time the waste dumping started were considered to show the effect of variations in the climatic conditions on the prediction of leachate quantity. In case 1, the starting time was the beginning of the wet season, case 2 started in the middle of the wet season, case 3 started at the beginning of the dry season and case 4 was implemented in the middle of dry season.

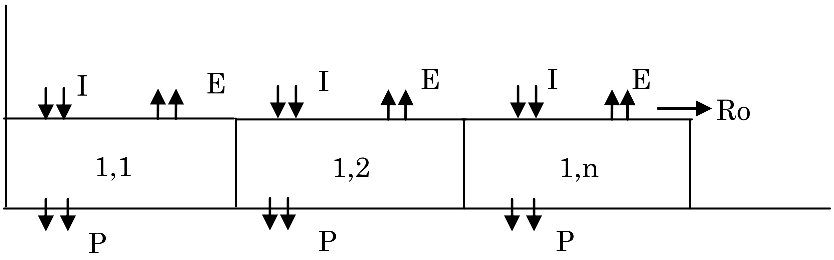

Figure 5.3. Illustration of the Waste Layer in the First Layer

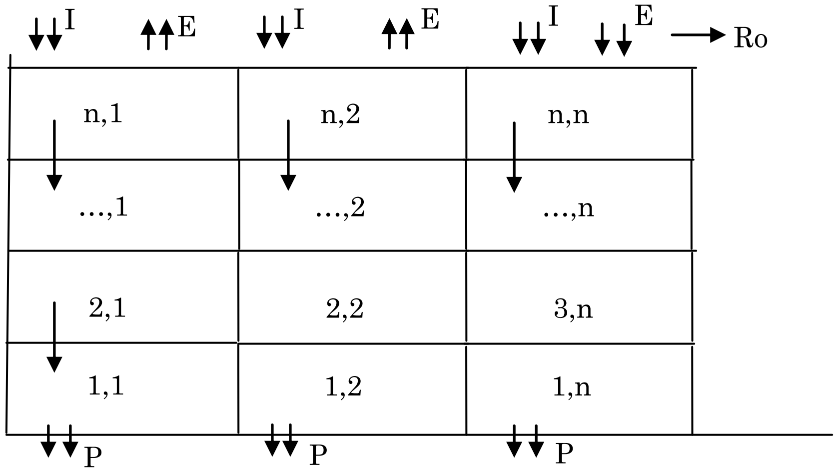

Figure 5.4. Illustration of the Waste Layer in the Uncover Application

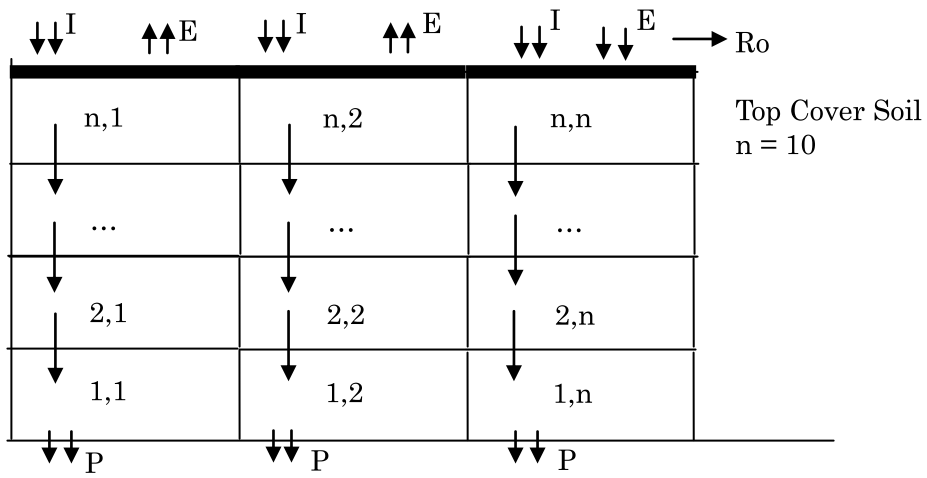

Figure 5.5. Illustration of the Waste Layer in the Top Cover Application

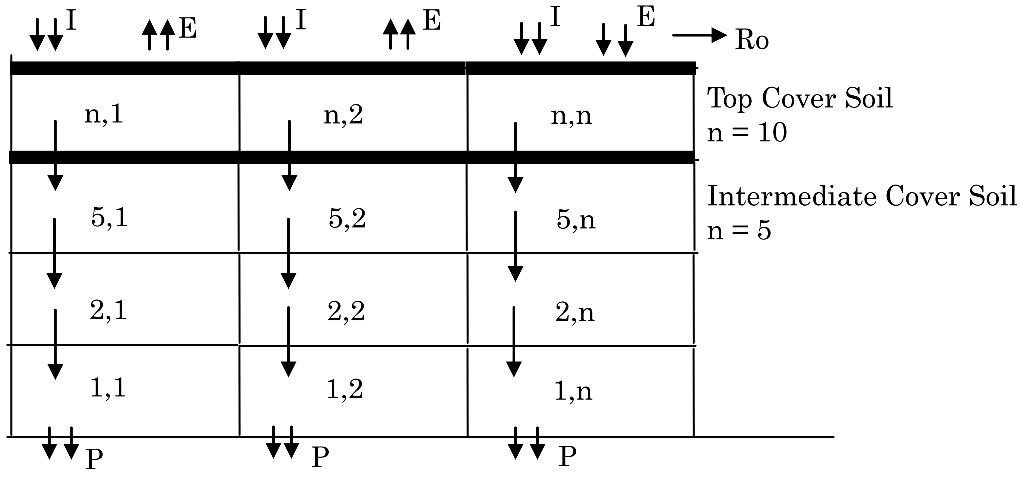

Figure 5.6. Illustration of the Waste Layer in the Intermediate Cover Application

5.3 Results and Discussion

5.3.1 Effect of Cover Soil and Beginning of Landfill Operation Time Leachate Quantity

a. Effect of cover soil from the beginning of wet season

As shown in Figure 5.7, the simulation without a cover soil on the landfill produced a high amount of leachate with high rainfall. The infiltration water was high and fulfilled the field capacity requirement of the waste because there was no cover preventing the rainfall from infiltrating the waste. The leachate occurrence was delayed because the amount of rainfall in the beginning of the wet season was not sufficient to fulfill the field capacity requirement of the waste and flow as leachate. After the rain started, the production of leachate was increased. After the wet season, the leachate was decreased but increased again after rainfall started in the wet season in the following years.

The result of a top cover soil in this figure shows a trend similar to the landfill without cover soil. The only difference was the amount of the leachate produced at the bottom of the landfill. The decrease in the leachate amount started after ten days, when the cover soil was applied to the top of the landfill. The difference occurred because the top cover soil prevented rainfall from infiltrating the waste. The amount of infiltration water in this case was lower than in the landfill without a cover.

The results of the intermediate cover soil simulation were different from the two other simulations after the cover soil was applied at 5 m (after 50 days). The leachate production was small compared with the simulations with only a top cover soil or without a cover soil. However, even the amount of leachate was small; the leachate production at the bottom of the landfill occurred more frequently than only the top cover soil or no cover soil landfill. In this case, the rainfall water was prevented from infiltrating the waste, firstly by the top cover soil, and then by the intermediate covers soil that prevented water from entering deeper layers of the landfill. Because of this, a low amount of leachate was produced at the bottom of the soil and took a longer time to occur.

b. Effect of a cover soil in the middle of wet season

In the middle of the wet season, as shown in Figure 5.8, the landfill without cover soil produced a high amount of leachate. The leachate production was increased by abundant rainfall. The production of the leachate decreased after the dry season started and increased again when rainfall started in the following wet season.

One hundred days after the top cover soil was implemented, the leachate production decreased compared with the results from the landfill without a cover. In the first 100 days, the leachate production was similar because the cover was not yet implemented. The leachate production was still lower compared with the landfill without a cover soil even though the wet season started in the following season

The intermediate cover produced a similar leachate pattern after the implementation of the cover in the 50 days after the waste was dumped for the first time. The production of leachate was still low in the dry season and in the following wet season, unlike the landfill without cover. The intermediate cover soil had a significant influence on leachate production because the intermediate cover withstood the water above the cover, which gradually infiltrated to the bottom layer and distributed the leachate over a longer time than the leachate was distributed in the top cover soil.

c. Effect of cover soil in the beginning of dry season

The simulation in the beginning of the dry season, as shown in Figure 5.9, produced a different pattern of leachate production. In the landfill without a cover, at the beginning of the waste disposal, leachate was still produced because there was still rainfall in this period. The leachate decreased in the following dry season. After the rainfall in the wet season, the production of leachate was not that high because the infiltration of water increased the waste water content to fulfill the field capacity requirement.

The application of the top cover soil produced a similar trend as the landfill without cover soil. The amount of leachate was lower than in the landfill without a cover because the water was prevented from infiltrating the waste. In the following wet season after the first dry season, leachate was produced more often because the water content below the cover fulfilled the field capacity requirement, whereas in the landfill without cover, there was insufficient water for infiltration because water was lost in the evaporation process

The intermediate cover soil produced different results of leachate generation. The cover soil prevented water from infiltrating the waste. The production of leachate was low compared with the top cover soil and the landfill without a cover. Even with the rainfall in the following wet season, the leachate was still low until the next dry and wet season. The results show the effect of implementing an intermediate cover soil on the production of leachate.

d. Effect of cover soil in the middle of dry season

An interesting result is shown in Figure 5.10 from the simulation in the middle of the dry season. In the landfill without cover, leachate was not produced until the rain came in the following wet season. In this period, the production was not that high or frequent because the infiltration water was used to fulfill the field capacity requirement that was lost due to the evaporation that occurred in the dry season. In the following wet season, the leachate production was not that high because the dry season period caused a decrease in the water content of the waste.

At the beginning of the waste disposal, the trend of the leachate production in the landfill with the cover soil was similar to the landfill without a cover soil until the following wet season. Furthermore, in the beginning of the following wet season, the leachate production was more frequent because the water content beneath the cover had already reached the field capacity of the waste and was not influenced by evaporation. The leachate production continued until the end of the wet season.

In the application of the intermediate cover in this period, the leachate was low even in the following wet season with abundant rainfall. Compared with the landfill without a cover soil, this result differed in the amount and frequency. The infiltration water was low and not sufficient to fulfill the field capacity requirement of the waste. However, compared with the top cover soil, the leachate showed the same trend but was produced in a smaller amount and was distributed more frequently.

e. Results of the starting time of the landfill operation in relation to the leachate *quantity*

The time the waste dumping started had a significant effect on the leachate produced a t the bottom of the landfill. The landfill without a cover soil showed that the starting time at the beginning of the wet season and in the middle of the wet season resulted in high and continuous leachate production compared with the beginning and middle of the dry season. The abundant rainfall caused high water infiltration and fulfilled the field capacity requirement of the waste. In the beginning and middle of the dry season, the infiltration of water was low and evaporation continued during the dry season. The infiltration that occurred in the following wet season only fulfilled the water content of the waste and was not sufficient for leachate production.

The top cover soil application showed the same trend in leachate production as the landfill without a cover soil in the beginning and middle of the wet season; only the amount of leachate was different. A lower amount of leachate was produced from the landfill without a cover. The top cover soil prevented a high amount of infiltration water from entering the waste. Different results occurred between the starting time at the beginning compared with the middle of the dry season. The leachate produced in the period from when the landfill was started was similar to the landfill without a cover because in the following wet season, the infiltration water was sufficient to fulfill the field capacity requirement of the waste and flow as leachate. The water content in the upper layer of the landfill was not influenced by evaporation. Once the water infiltrated, the field capacity was easily reached and the water flowed as leachate. Because of this, in the following wet season and after the dry season passed, more leachate was produced than in the landfill without a cover.

The intermediate cover soil decreased the leachate production for each time from when the waste disposal started compared with the application of the top cover soil and the landfill without a cover. A similar trend in leachate generation observed with the top cover soil application occurred in the beginning and middle of the wet season. The intermediate cover prevented high amounts of infiltration water from entering the waste. In the beginning and the middle of the dry season, the intermediate cover prevented evaporation and infiltration of rainfall water from entering the waste. This continued in the following wet season after the dry season passed. Leachate generated in the following wet season was low because the infiltration water was not sufficient to fulfill the field capacity requirement even though there was abundant rainfall. However, the leachate was produced more frequently compared with the top cover soil application.

f. Discussion

The simulation results show the effect of the application of the cover soil on leachate quantity. The application of the cover soil in the top layer prevented rainfall water from entering the landfill. The intermediate cover soil was effective in preventing high amounts of leachate. The intermediate cover soil held the water in the waste for longer and distributed the leachate flow more evenly but there was a smaller variation in the amount produced compared with the top cover soil. Implementation of the starting time for dumping the waste showed a similar trend in the beginning and the middle of the wet season. The abundant rainfall in this period contributed to the production of leachate when the waste dumping started; however, the cover soil application was sufficient to prevent infiltrated water from entering the waste. In the beginning and middle of the dry season, the leachate production was low until the rainfall started in the following wet season. The implementation of the cover soil was effective in preventing infiltrated water from entering the waste in the following wet season.

The comparisons in Table 5.1 show the leachate production for one-year periods. The leachate generation was stable in the second year after the waste was dumped. The leachate production in the landfill without cover (un-cover) was higher than the landfill with the application of top cover soil and intermediate cover soil. The application of top and intermediate cover soil reduced the amount of leachate in the first year of waste disposal by 1.7 times at the beginning of the wet season; 1.1 times in the middle of the wet season; 1.3times at the beginning of the dry season and 2.7 times in the middle of the dry season compared with the landfill without cover soil.In the second and third year of the prediction, the reduction was similar for each starting time of the waste disposal, i.e. 1.2 times.

Table 5.1. The Leachate Production at the Bottom of Landfill (in m^3)

Timming	Type of cover	1 st year	2 nd year	3 rd year
Beginning of wet season	Un-cover	4741,6	2425,6	2425,6
	Cover	2783,3	1926,0	1926,0
	Intermidiate	2658,5	1926,0	1926,0
Middle of wet season	Un-cover	6617,1	2425,6	2425,6
	Cover	6286,3	1926,0	1926,0
	Intermidiate	6154,0	1926,0	1926,0
Beginning of dry season	Un-cover	4401,9	2425,6	2425,6
	Cover	3298,0	1926,0	1926,0
	Intermidiate	3285,3	1926,0	1926,0
Middle of dry season	Un-cover	1437,1	2425,6	2425,6
	Cover	530,0	1926,0	1926,0
	Intermidiate	530,0	1926,0	1926,0

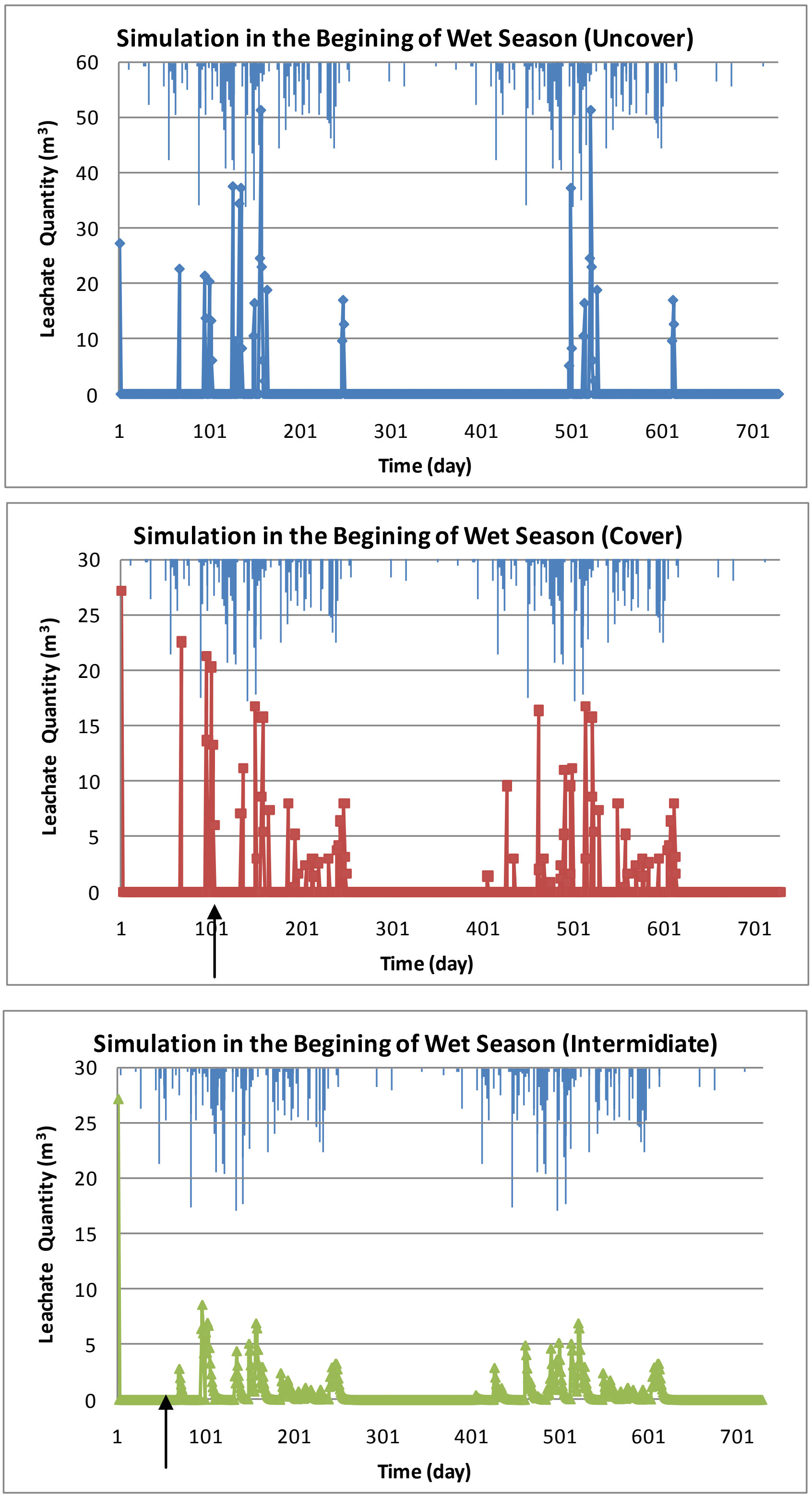

Figure 5.7. Leachate Prediction Result from the Beginning of Wet Season

*↑ = Application of cover soil

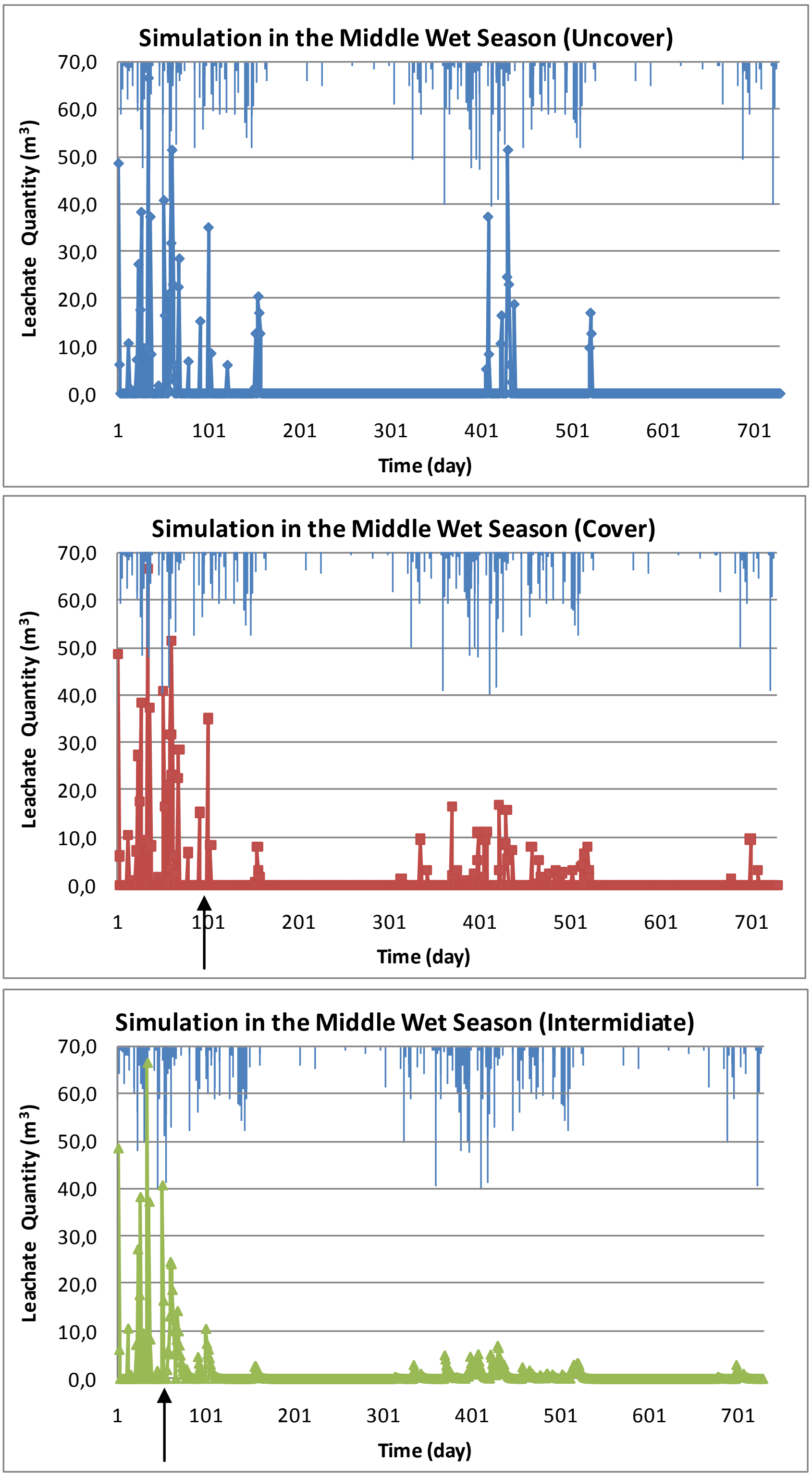

Figure 5.8. Leachate Prediction Result from the Middle of Wet Season

*↑ = Application of cover soil

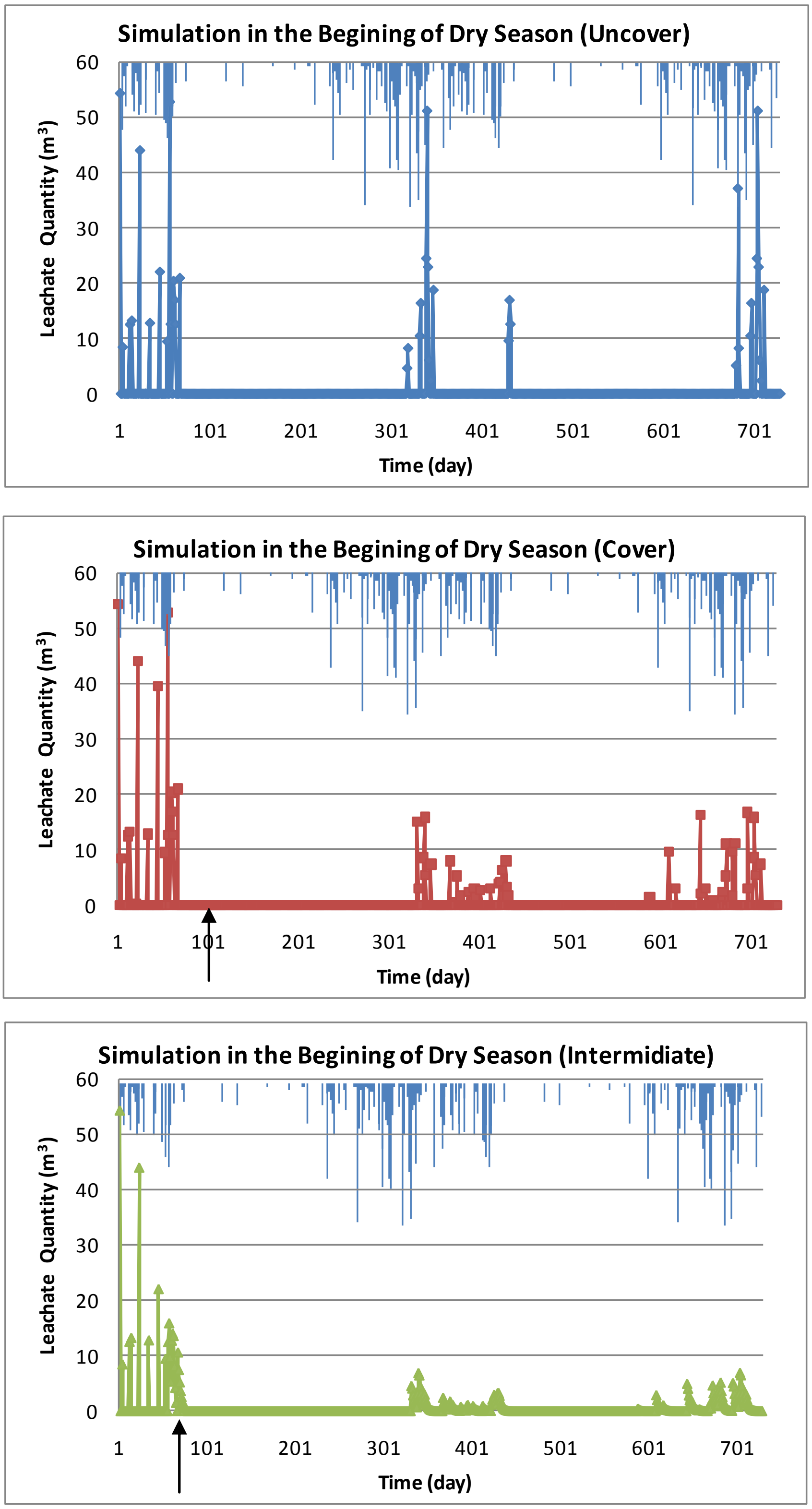

Figure 5.9. Leachate Prediction Result from the Beginning of Dry Season

*↑ = Application of cover soil

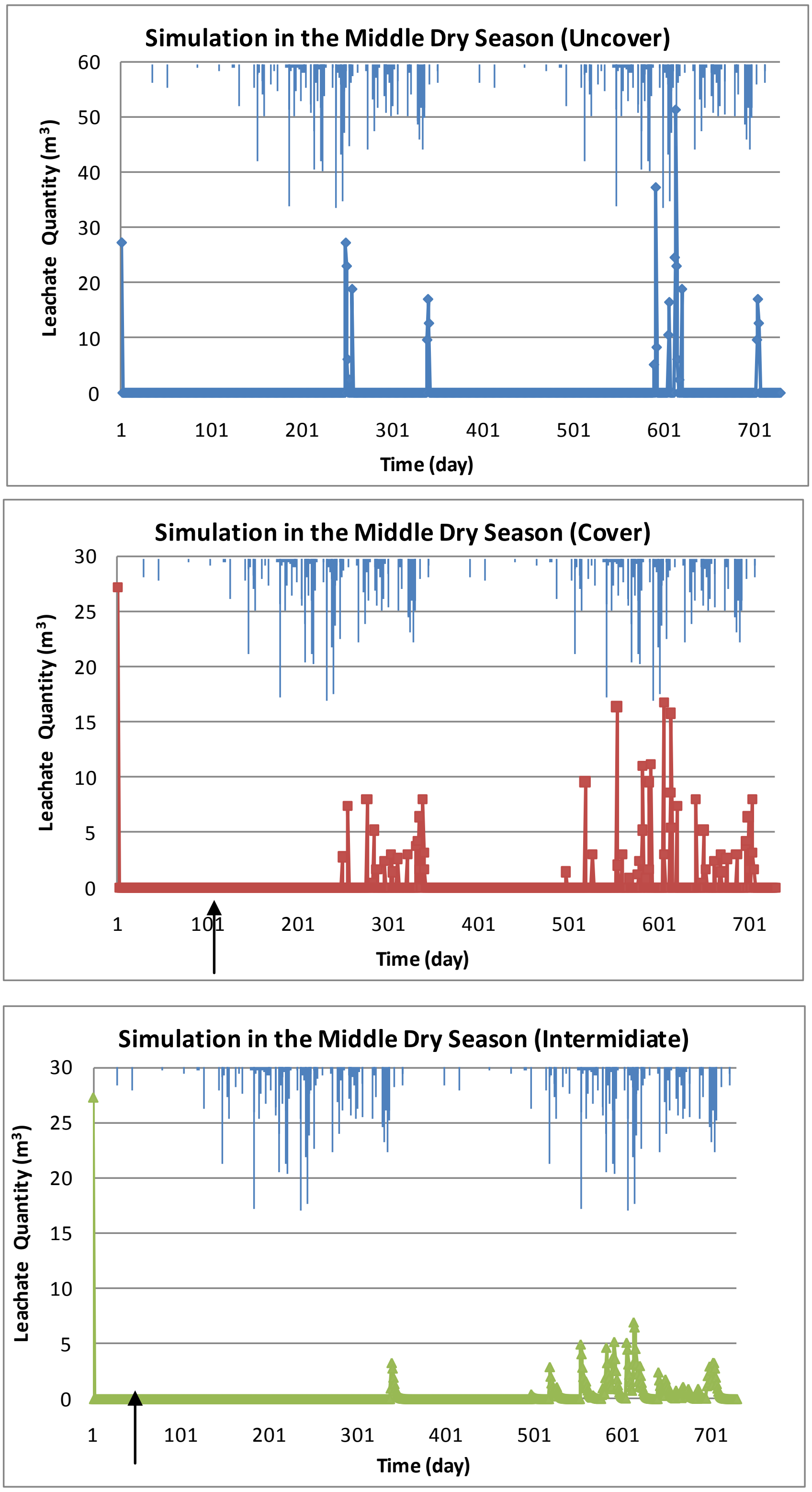

Figure 5.10. Leachate Prediction Result from the Middle of Dry Season

*↑ = Application of cover soil

5.3.2 The Effect of the Cover Soil and the Starting Timeof the Landfill Operation on the Leachate Quality

a. Effect of cover soil on the leachate quality

As shown in Figure 5.11, at the beginning of the wet season, the trend in the leachate quality was similar between the landfill without cover soil and the landfill with the application of top cover soil. The low water content of the waste, due to a lack of rainfall at the beginning of the dumping process, produced a delay in the degradation process in the landfill. The production of leachate was delayed until approximately 50 days. The degradation occurred later because the infiltration water was not sufficient to enter the landfill and fulfill the water content requirement needed for degradation. The application of the intermediate cover soil produced the same result as the open dumping and the top cover soil landfill. In this case, the high leachate concentration was similar in the landfill without cover soil and in the application of the top and intermediate cover soil.

Figure 5.12 shows that at the beginning of the dry season and in the middle of the wet season, the degradation results were similar, and the trend and the concentration at the bottom of the landfill were slightly similar. The implementation of the cover soil in the top layer and intermediate layer were not significantly different from the landfill without cover soil. In this case, the abundant rainwater was sufficient to fulfill the conditions for degradation, and a similar, high concentration was produced.

There was no significant effect of the application of the cover soil at the beginning of dry season, as shown in Figure 5.13. This condition did not differ from the condition in the middle of the wet season. The landfill without a cover, the application of a top cover soil and intermediate cover soil produced the same trend and high leachate concentration at the bottom of the landfill. This condition occurred because in each simulation, the water content was sufficient to maintain the conditions needed for the degradation process.

For the starting time in the middle of the dry season, as shown in Figure 5.14, the result from the landfill without a cover showed that the concentration was low when the dumping started. At this time, there was insufficient rainfall to change the water content. The concentration increase was delayed for more than 200 days from when the dumping started. The top cover soil layer needed more time to increase the concentration at the bottom of the landfill. A different result was shown in the application of the intermediate cover. The delay in the increase in the concentration was 250 days. This shows that degradation did not occur in this period. The delay in the intermediate cover soil application was longer, i.e., 300 days. The intermediate cover soil prevented favorable conditions for the degradation process for a longer period than the landfills without a cover and the application of a top cover soil. However, the high concentration in the leachateat the beginning of the landfill operation was similar.

b.Effect of the starting time of the landfill operation in relation to the leachate quality

As shown in Figure 5.11 to 5.14, the landfill without a cover soil showed a similar trend in the increased leachate concentration at the bottom of the landfill in the middle of the wet season and at the beginning of the dry season. The leachate concentration increased from when the waste was first dumped. Sufficient rainfall water infiltrated the waste at these times to provide suitable conditions for the degradation process.

At the beginning of the wet season, an increase the leachate concentration was delayed for approximately 50 days before following the same trend observed in the middle of the wet season and beginning of the dry season. The delay occurred because the water content was less than 50%. The infiltration water was not sufficient to fulfill the 50% water content condition because there were few rainfall events. The few rainfall events in the middle of the dry season caused a delay in an increase in the concentration until approximately 200 days. An increase in the concentration occurred after the rainfall started in the following wet season.

The same trend was observed for the application of the top cover soil as shown in Figure 5.11 to 5.14. At the beginning of the landfill operation, the top cover soil application produced the same result as the landfill without a cover. The time delay in the middle of the dry season occurred at approximately250 days after the waste was dumped. There was no difference compared with the landfill without cover at approximately 50 days.

The result of the application of the intermediate cover soil showed that the trend and timing of the increase in the concentration at the bottom of the landfill was similar to the landfill without a cover and the landfill with the application of the top cover soil. A difference in the delay in the increase in the concentration occurred in the middle of the dry season, after approximately 300 days. The infiltration water was prevented by the intermediate cover soil from entering the waste and fulfilling the conditions for degradation for a longer period than with the application of the top cover soil.

Furthermore, the high concentration in the leachate contained in the bottom of the landfill from the beginning of the landfill operation was similar. The results from Figure 5.7 to 5.10 show that the concentration that was produced was similar and that the cover soil application did not influence the high leachate concentration at the bottom of the landfill.

c. Discussion

The quality of the leachate in the simulation model depended on the timing and initial condition of the leachate. The infiltration water from rainfall at the landfill site played a role in determining the leachate quality as a result of the biodegradation process in the landfill. Furthermore, the water content of the waste depended on the infiltration water.

The biodegradation process in the waste depended on the water content. According to Chapter 3, a wastewater content below 50% resulted in slightly slower biodegradation. Since the water content in the landfill waste was influenced by the infiltration water from rainfall, the biodegradation process in the waste was directly related to the process of infiltration. In the upper layer of the landfill, evaporation influenced the water content. In the dry season, the water content decreased and reached zero by the end of the season. Degradation did not occur in this period.

The prediction of the leachate quality showed that the effect of the application of cover soil was not that significant for the leachate concentration at the bottom of the landfill. The top cover soil and intermediate cover soil application prevented evaporation from the waste. The water content was stable under these conditions. The stable condition provided suitable conditions for degradation. The BOD concentration at the bottom of the landfill site was not that different, except that the starting time of degradation was delayed in the case where the waste was dumped in the middle of the dry season. In the condition without cover soil, the water content in the upper layer was low and degradation ceased. However, the influence of evaporation only occurred in the top layer, and degradation occurred in the layer below 0.5 m.

The time that the waste dumping started had no significant influence on the leachate concentration at the bottom of the landfill, only the timing of the leachate production was different. The landfill without a cover in the middle of the wet season and at the beginning of the dry season had a similar trend and timing of the increase in concentration. This condition occurred because there was still water available for the degradation process. At the beginning of the wet season, the increase in the leachate concentration was delayed until 50 days because during that time, the rainfall amount was still low and not sufficient to increase the water content to50%. In the middle of dry season, the delay increased to approximately 300 days. The delay in the increase of the leachate was caused by insufficient infiltration water from rainfall that was needed to support the degradation process.

The results of the leachate quality prediction can be summarized and used as the basis for starting a waste dumping operation. Since the application of the top cover soil and intermediate cover had similar patterns of degradation compared with the open dumping landfill, the application of the top cover soil and intermediate cover can be implemented at the beginning of the dry season and in the middle of the wet season. The intermediate cover is not recommended for application at the beginning of the wet season because degradation was low when the cover was applied. In the middle of the dry season, application of the top cover soil can be delayed until rainfall starts to provide conditions suitable for the degradation process. The BOD concentration was the same for the conditions without a cover soil, and the application of an intermediate cover soil is not recommended because it will delay the degradation process for a long time.

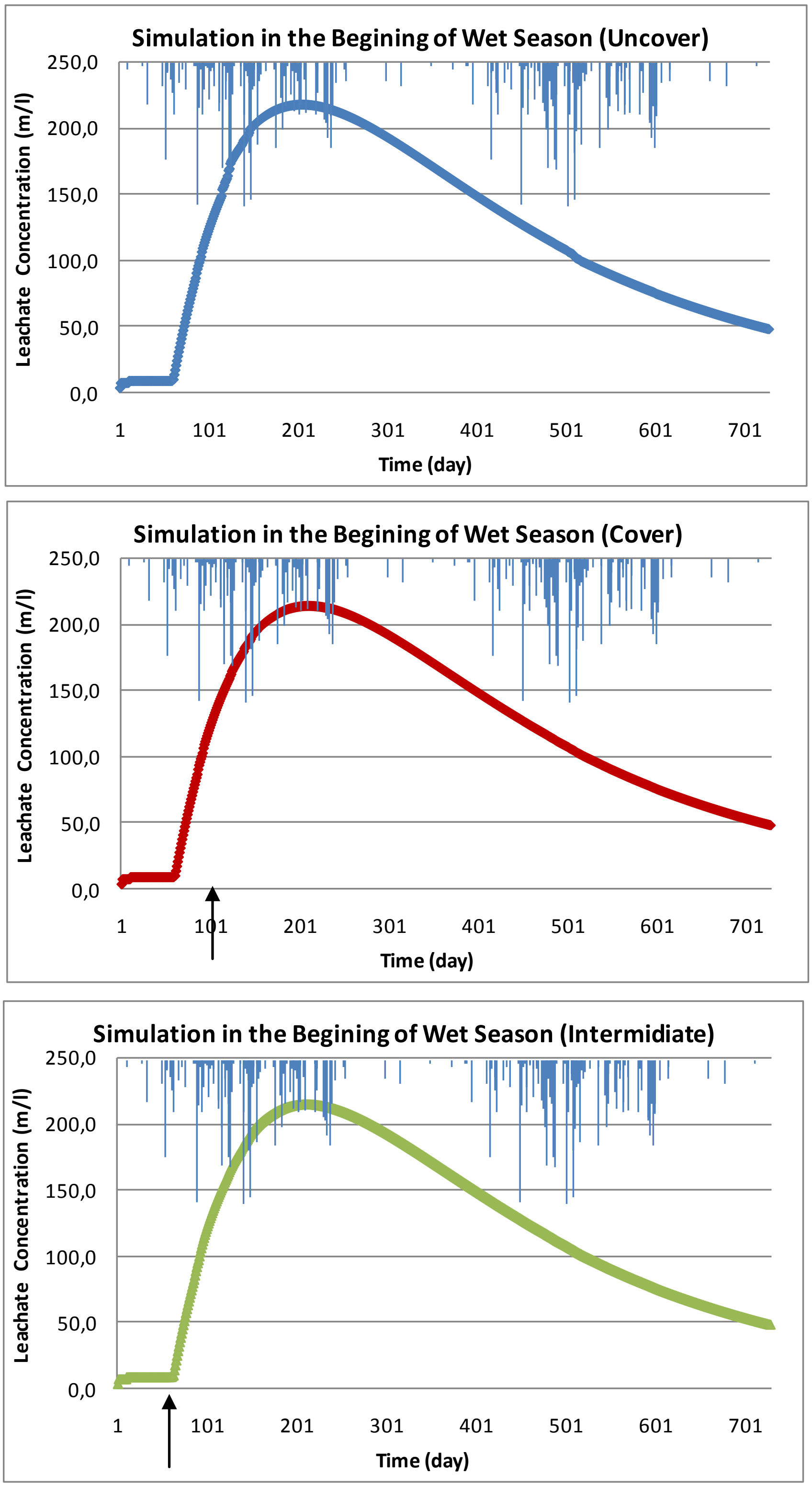

Figure 5.11. Leachate Quality Prediction Result for the Beginning of Wet Season

*↑ = Application of cover soil

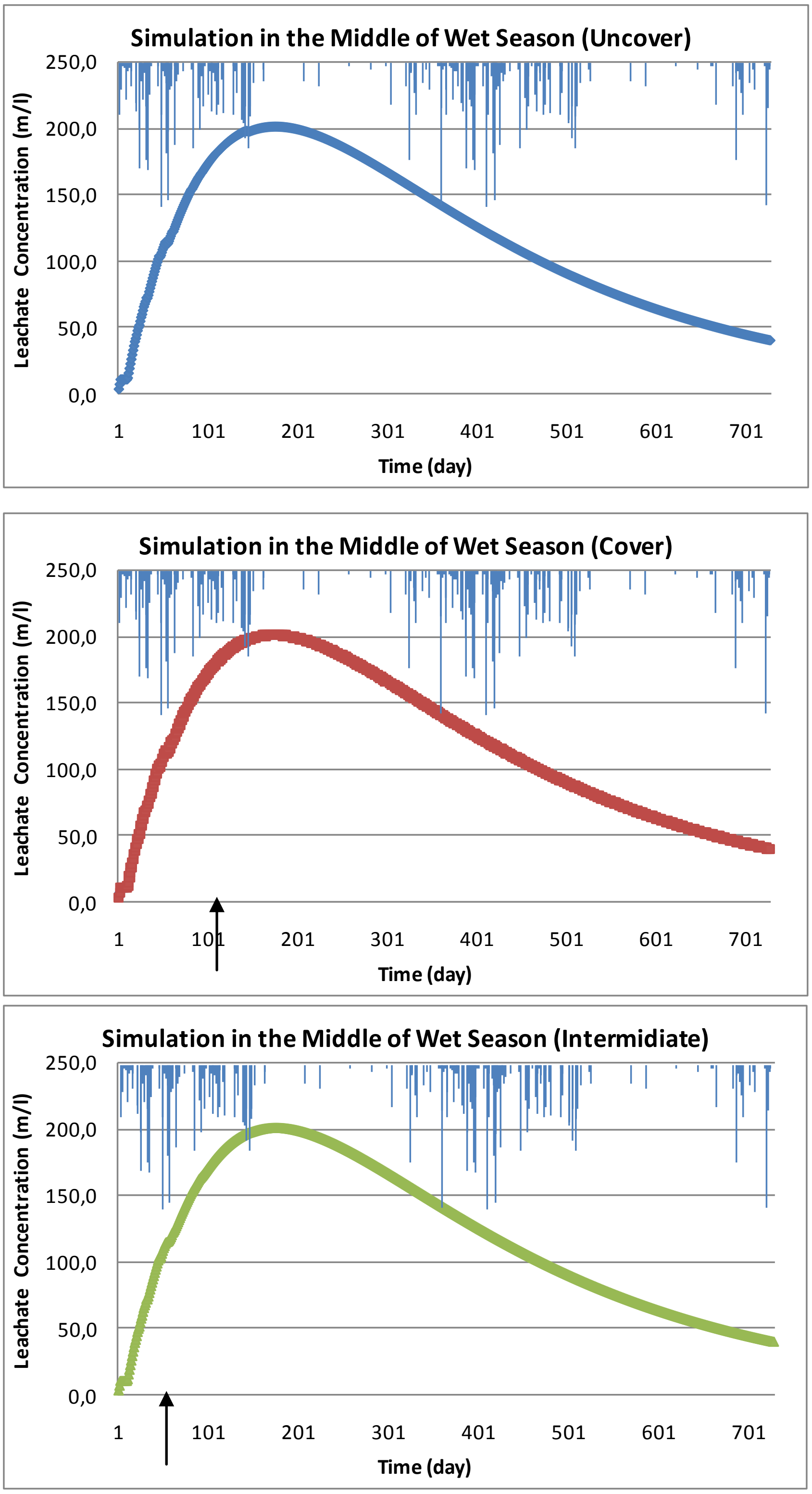

Figure 5.12. Leachate Quality Prediction Result for the Middle of Wet Season

*↑ = Application of cover soil

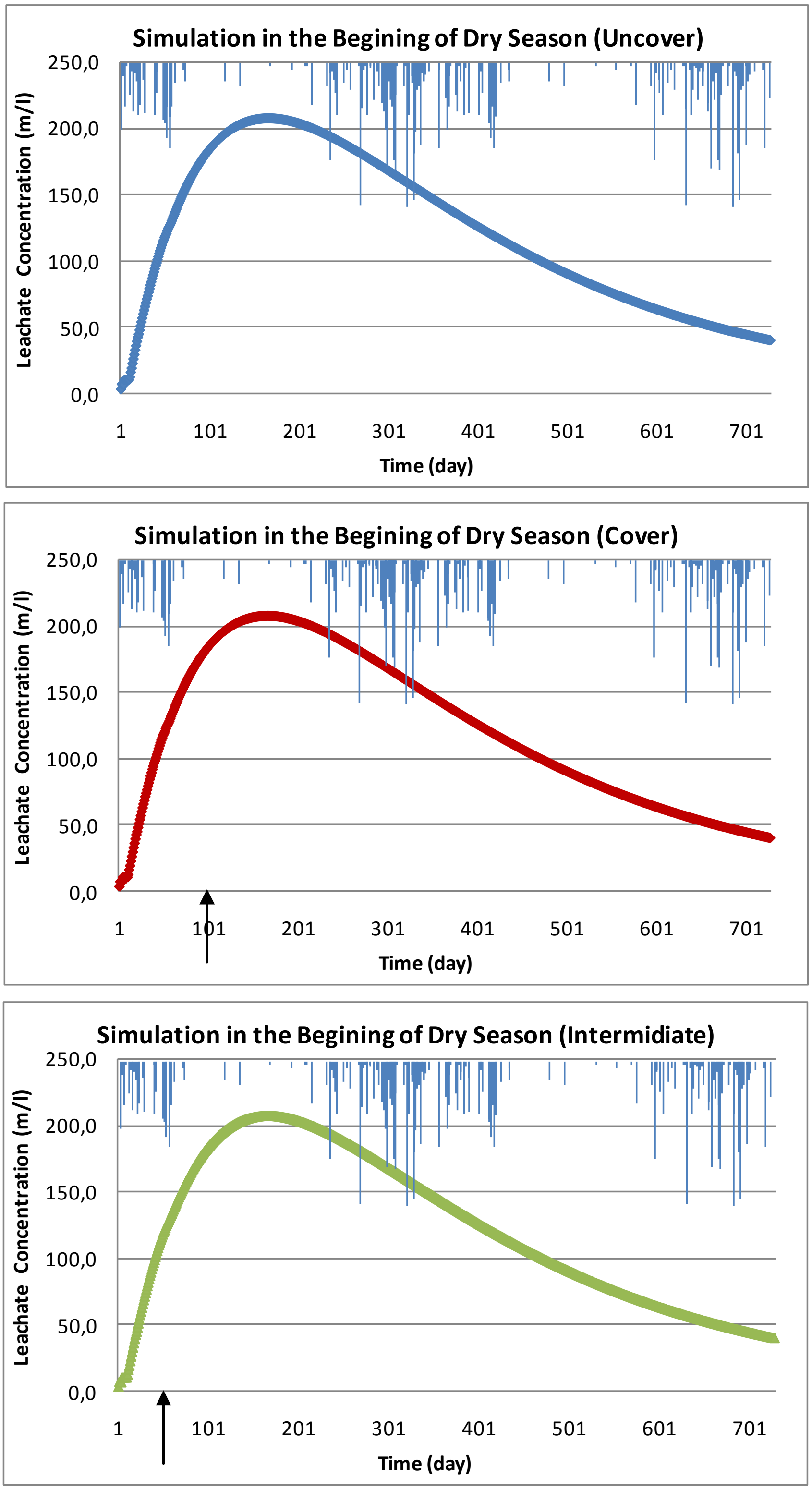

Figure 5.13. Leachate Quality Prediction Result for the Beginning of Dry Season

*↑ = Application of cover soil

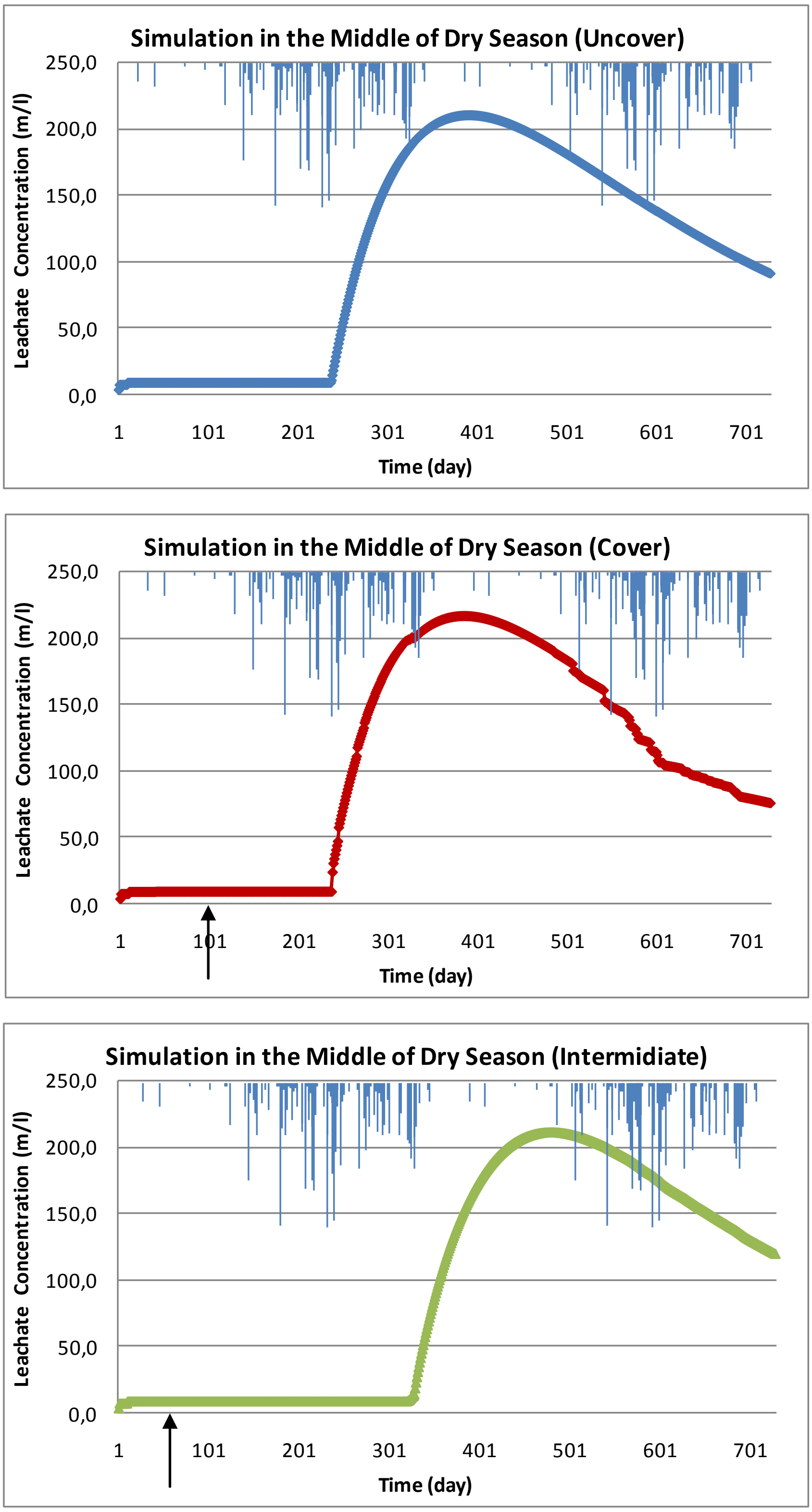

Figure 5.14. Leachate Quality Prediction Result for the Middle of Dry Season

*↑ = Application of cover soil

5.3.3 Comparison with the other area

The result of water balance method in this simulation was similar to other results of leachate generation in other areas in Indonesia (Samin et al., 2012) and other regions with a tropical climate (Chiemchaisri et al., 2002).Since the rainfall pattern and temperature fluctuations were similar, the leachate generation pattern was similar. The leachate generation was high in the wet season and decreased in the dry season.

Arid and temperate regions have different rainfall distributions throughout a year. In tropical regions, rainfall only occurs in the wet season (April to October). In arid regions, the temperatures are higher and the rainfall is lower. The infiltration and the evaporation rate are different because of the different amounts of leachate (Altaouqi, 2012). In arid areas, the amount of leachate is lower than in tropical climates.

In temperate regions, rainfall is distributed throughoutthe year, and no single rainfall occurrence has a high amount of rainfall. The temperature of the area is divided into four seasons with extreme differences. The differences in the rainfall and temperature would affect the leachate generation. In this region, leachate would be produced throughout the year but in average amounts (Teresa et al., 2003; Tatsi et al., 2002). The leachate generation was different from the tropical area where the leachate was concentrated only in the wet season. Temperature highs in the summer and lows in the winter could affect evaporation that is related to the process of leachate generation.

5.3.4 Design of leachate treatment in Indonesia

In Indonesia, the landfill sites that use the open dumping system still occupy more than 79% of all landfills. The other types are controlled landfills (15%) and sanitary landfills (6%). Out of all the existing landfills, only 42% have a leachate treatment plant, where 31% use a physical treatment method, 9% use a chemical treatment method and 2% use a biological treatment method (Hermana, 2012;MoE, 2008). This shows that landfills in Indonesia still have in adequate leachate treatment.

The usual method was physical treatment, where ponds are used to process the leachate sediment. The process uses anaerobic ponds, stabilization ponds, maturation ponds, and bio-filter ponds. The dimensions of the ponds in treatment plants are directly related to the volume of the leachate generated from a landfill

According to the Indonesian National Standard for the construction and operation of landfills (MoE, 2001), the calculation of the leachate generation is based on the water balance method using the HELP model, where the sanitary landfill (i.e., a landfill with a top cover soil) is used as the typical model. The standard mentions that the leachate generated from a landfill is produced from 20 – 30% of the rainfall that occurs.

Since a large number of landfills exist without a cover soil, it is necessary to complement the National Standard with a model to predict the leachate generated in a landfill without a cover soil. According to the water balance calculation, the leachate was generated in large amounts in the landfill without a cover, and in the landfill with a cover soil, the annual amount of leachate produced was approximately70% of the value from the landfill without a cover.

Consideration of the time the dumping process starts and the application of a top or intermediate cover soil is one aspect that can be added to the Indonesian National Standard for the construction and operation of landfills. The variation inthe rainfall and climatic conditions significantly influenced the starting time of the degradation of the waste. The result of the leachate quantity and quality prediction can be used as a factor for determining the application of a cover soil.

Since the leachate treatment plant capacity depends on the leachate quantity and quality, it is necessary to consider the type of landfill (i.e., without a cover soil, top cover soil, or intermediate cover soil). The starting time of the dumping of the waste is one factor to consider. The combination of the application of the cover soil and the timing of the waste disposal will produce different patterns of leachate quantity and quality. When planning a leachate treatment plant, the application of a cover soil and the starting time of the dumping of the waste must be considered in order to determine the appropriate dimensions and capacity of the landfill.

5.4 Conclusion

The combination of the water balance and degradation model in this paper was carried out at the landfill site from the beginning of the waste disposal. A conclusion derived from the model was that leachate generation depends on the climate in tropical areas, especially under Indonesian conditions. The conclusions obtained were:

1. In the prediction of the quantity of the leachate, the application of the top and intermediate cover soil reduced the amount of leachate in the waste in the first year by1.7 times atthe beginning of the wet season; 1.1 times in the middle of

the wet season; 1.3 times at the beginning of the dry season and 2.7 times in the middle of the dry season compared with the landfill without a cover soil. In the second and the third year of the prediction, however, the reduction was similar for each starting time of the waste disposal, i.e., 1.2 times.

2. The intermediate cover soil held the water in the waste for longer and distributedthe leachate flow more evenly but there was a smaller variation in the amount produced compared with the top cover soil.
3. The cover application caused a delay in thetiming of the increase in the BOD concentration at the beginning of the dry season. The time delay in the intermediate cover application was 100 days compared with the no-cover soil. In case of beginning and middle of wet season, and case of middle of dry season, the effect of cover application did not cause in the delay. There was no difference in maximum BOD concentration between no-cover and cover application for any dumping time.
4. Consideration of the time to start the dumping process and the application of a top or intermediate cover soil is one aspect that can be added to the Indonesian National Standard for the construction and operation of landfills considering the influence of these factors on the leachate quantity and quality.

5.5 References

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Chapter 6 General Conclusion

6.1 Research Summary

The objectives of this research were to evaluate the solid waste management of Malang Municipality in Indonesia and to predict the quantity and quality of the leachate based on the climatic conditions, in order to form a useful basis for increasing solid waste management performance and to develop a leachate treatment plant in Indonesia. In general, the results of this study can be summarized as follows:

1. The result of the SWOT analysis showed that a strategy to increase the government's role, the participation of the inhabitants, and landfill management conditions can be applied to increase the performance the solid waste management in Malang Municipality. One of the strategies related to the landfill management was to predict the leachate quantity and quality that was appropriate for the landfill site in this municipality accounting for the influence of local factors and using a simple method in the approach.
2. In the case of the effect of the water content on the gas generated as an indicator of the degradation activity, the critical water content suitable for the degradation process was 50%. Below the critical water content, the degradation activity was reduced.
3. The column experiment showed that the evaporation of the waste occurred only in the top layer of the waste. The water content distribution in deeper layers was influenced by the water movement. The results from this study were compared with the results from afield investigation in an actual landfill in Indonesia. The water content distribution at the end of the experiment was similar to the water content obtained from the field investigation.
4. In the prediction of the quantity of the leachate, the application of the top and intermediate cover soil reduced the amount of leachate in the first year the waste was dumped by 1.7 times at the beginning of the wet season, 1.1 times in the middle of the wet season, 1.3 times at the beginning of the dry season and 2.7 times in the middle of the dry season compared with the landfill without a cover soil application. In the second and the third year of the prediction, however, the reduction was similar for each starting time of the waste disposal, i.e., 1.2 times.

5. The intermediate cover soil held the water in the waste for longer and distributed the leachate flow more evenly but in smaller amounts compared with the top cover soil.
6. The cover application caused in the delay in the timing of the increase in the BOD concentration at the beginning of the dry season. The time delay in the intermediate cover application was 100 days compared with theno-cover soil. In case of beginning and middle of wet season, and case of middle of dry season, the effect of cover application did not cause in the delay. There was no difference in maximum BOD concentration between no-cover and cover application for any dumping time.
7. Consideration of the time to apply the cover soil and the low variation in the leachate produced from the intermediate cover soil application is one aspect that can be used for the leachate treatment plant plan and can be added to the Indonesian National Standard for the construction and operation of landfills.

6.2 Future Work

This study provides the basic research results of the prediction of the quantity and quality of the leachate under tropical climatic conditions. However, further studies should be carried out to advance the understanding of the leachate generation prediction in a tropical climate, as follows:

1. The SWOT analysis was the method used as a tool to enhance the performance of the solid waste management in Malang Municipality. It is necessary to expand the utility of the tool with respect to increasing the governmental role, participation of the inhabitants and landfill conditions for the solid waste management in the municipality, as well as other factors that should be included in integrated solid waste management.
2. The model of water distribution in the landfill was influenced by the several factors, such as the density of the waste and the evaporation process. It would be interesting to continue investigating the model of the water distribution with several different conditions of the influencing factors. The interaction between the factors could be used to figure out the behavior of the water distribution in a landfill.

3. For valid prediction of the quantity and quality of the leachate based on the climatic conditions, it is necessary to conduct field research to compare with the model prediction results.

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