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Comparative Study of Physical and Chemical Characteristics of the Mechanically and Biologically Treated Waste from Luxembourg, Germany and Thailand

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Abstract

Mechanical and Biological Treatment (MBT) generally aims to reduce the amount of solid waste and emissions in landfills and enhance the recoveries. MBT technology has been studied in various countries in Europe and Asia. Techniques of solid waste treatment are distinctly different in the study areas. A better understanding of MBT waste characteristics can lead to an optimization of the MBT technology.
For a sustainable waste management, it is essential to determine the characteristics of the final MBT waste, the effectiveness of the treatment system as well as the potential application of the final material regarding future utilization. This study aims to define and compare the characteristics of the final MBT materials in the following countries:

- Luxembourg (using a high degree technology):
  Fridhaff in Diekirch/Erpeldange
- Germany (using a well regulated technology):
  Singhofen in Rhein-Lahn district
- Thailand (using a low cost technology):
  Phitsanulok in Phitsanulok province

The three countries were chosen for this comparative study due to their unique performance in the MBT implementation. The samples were taken from the composting heaps of the final treatment process prior to sending them to landfills, using a random sampling standard strategy from August 2008 onwards. The size of the sample was reduced to manageable sizes before characterization. The size reduction was achieved by the quartering method.

The samples were first analyzed for the size fraction on the day of collection. They were screened into three fractions by the method of dry sieving: small size with a diameter of < 10 mm, medium size with a diameter of $10 - 40$ mm and large size with a diameter of > 40 mm. These fractions were further analyzed for their physical and chemical parameters such as particle size distribution (total into 12 size fractions), particle shape, porosity, composition, water content, water retention capacity and respiratory activity. The extracted eluate was analyzed for pH-value, heavy metals (lead, cadmium and arsenic), chemical oxygen demand, ammonium, sulfate and chloride. In order to describe and evaluate the potential application of the small size material as a final cover of landfills, the fraction of small size samples were tested for the geotechnical properties as well. The geotechnical parameters were the compaction test, permeability test and shear strength test. The detailed description of the treatment facilities and methods of the study areas were included in the results.

The samples from the three countries are visibly smaller than waste without pretreatment. Maximum particle size is found to be less than 100 mm. The samples are found to consist of dust to coarse fractions. The small size with a diameter of < 10 mm was highest in the sample from Germany (average 60% by weight), secondly in the sample from Luxembourg (average 43% by weight) and lowest in the sample from Thailand (average 15% by weight). The content of biodegradable material generally increased with decreasing particle sizes.

Primary components are organic, plastics, fibrous materials and inert materials (glass and ceramics). The percentage of each components greatly depends on the MBT process of each country. Other important characteristics are significantly reduced water content, reduced total organic carbon and reduced potential heavy metals. The geotechnical results show that the small fraction is highly compact, has a low permeability and lot of water adsorbed material.

The utilization of MBT material in this study shows a good trend as it proved to be a safe material which contained very low amounts of loadings and concentrations of chemical oxygen demand, ammonium, and heavy metals. The organic part can be developed to be a soil conditioner. It is also suitably utilized as a bio-filter layer in the final cover of landfill or as a temporary cover during the MBT process.

This study showed how to identify the most appropriate technology for municipal solid waste disposal through the study of waste characterization.

Keywords: Mechanical and biological treatment, pretreated waste, characteristics of pre-treated waste, MBT technology, Luxembourg, Germany, Thailand

Zusammenfassung

Mechanische und Biologische Abfallbehandlung (MBA) zielt generell darauf den Betrag von festen Abfällen und Emissionen auf Deponien zu verringern und zur Verbesserung der Regenerierung der Böden. Die MBA-Technologie wurde in verschiedenen Ländern im Rahmen der europäischen und asiatischen Ländern untersucht. Techniken der Behandlung fester Abfälle sind deutlich unterschiedlich in den verschiedenen Untersuchungsgebieten.

Ein besseres Verständnis der Eigenschaften von MBA Abfällen kann zu einer Optimierung der MBA-Technologie führen. Für eine nachhaltige Abfallwirtschaft, ist es wichtig, die Merkmale der endgültigen MBA Abfälle zu ermitteln, die Wirksamkeit der Behandlungs-Systeme und die mögliche Anwendung des fertigen Materials hinsichtlich der künftigen Nutzung. Diese Studie hat zum Ziel die Merkmale der endgültigen MBA Materialien in den folgenden Ländern zu vergleichen:

- Luxemburg (mit einem hohen Grad an Technologie):
  Fridhaff in Diekirch/Erpeldange
- Deutschland (mit einer gut geregelten Technologie):
  Singhofen in Rhein-Lahn Kreis
- Thailand (mit einer Low-cost Technologie):
  Phitsanulok in Phitsanulok Provinz

Die drei Länder wurden für diese vergleichende Studie aufgrund ihrer einzigartigen Leistungen in der MBA Umsetzung ausgewählt. Die Proben wurden nach dem letzten Behandlungsprozess aus der Kompostierung heraus genommen bevor sie zur Deponie gesendet wurden. Die Proben wurden nach einer Standard Zufallsstrategie seit August 2008 aus der kompostierung herausgenommen. Die Größe der Stichprobe wurde auf eine benutzbare Menge reduziert um Charakterisierung zur ermöglichen. Die Verkleinerung wurde erreicht durch die vier Mengen Methode.

Die Proben wurden nach dem jeweils endgültigen Verarbeitungsprozesses aus den Komposthaufen genommen, bevor sie auf die Deponien gesendet wurden. Die Proben wurden durch Trocken-Siebung in drei Gruppen getrennt: eine Feinfraktion mit einem Durchmesser von < 10 mm, eine mittlere Fraktion mit einem Durchmesser von 10 bis 40 mm und eine grobe mit einem Durchmesser von > 40 mm. Die Proben wurden auf ihre physikalischen und chemischen Parameter wie Partikelgröße, Partikelform, Porosität, Zusammensetzung, Wassergehalt, Wasserrückhaltevermögen und Atmungsaktivität untersucht. Die extrahierten Eluate wurden auf folgende Werte untersucht: pH-Wert, Schwermetalle, chemischer Sauerstoffbedarf, Ammonium, Sulfat und Chlorid. Um die mögliche Anwendung der Feinfaktion als Material für eine endgültige Deponieabdeckung zu bewerten, wurden die Proben auch auf ihre geotechnischen Eigenschaften getestet. Die geotechnischen Parameter waren die Verdichtung, Durchlässigkeit und Scherfestigkeit.

Die MBA-Proben aus den drei Ländern sind deutlich kleiner als Abfälle ohne Vorbehandlung. Die maximale Partikelgröße beträgt weniger als 100 mm. Die Korngrößen reichen von Schluff bis Kies-größe.

Die Feinfacktion mit einem Durchmesser von < 10 mm war am größten in der Probe aus Deutschland (durchschnittlich 60 Gew.%), gefolgt von der Probe aus Luxemburg (durchschnittlich 43 Gew.%) und am niedrigsten in der Probe aus Thailand (durchschnittlich 15 Gew.%). Der Gehalt an biologisch abbaubarem Material erhöht sich in der Regel mit einer abnehmenden Partikelgröße. Die Hauptkomponenten sind Kompost, Kunststoffe, Faserstoffe und inerte Materialien (Glas und Keramik). Der Anteil der einzelnen Komponenten hängt stark von dem MBA-Prozess des jeweiligen Landes ab. Weitere wichtige Merkmale sind ein signifikant reduzierter Wassergehalt, ein reduzierter Gesamtanteil an organischem Kohlenstoff und reduzierte Schwermetall gehalte. Die geotechnischen Ergebnisse zeigen, dass die feinen Fraktionen sehr kompakt sind, eine geringe Durchlässigkeit haben und viel Wasser adsorbieren.

Die Nutzung von MBA Material in dieser Studie zeigt eine deutlich Tendenz, dass es sich um ein sicheres Material handelt, welches sehr geringe Mengen an Belastungen wie Kohlenstoff, Ammonium und Schwermetalle enthält. Der Kompostteil kann zu einem Bodenverbesserer entwickelt werden. Er ist auch geeignet als eine Biofilterschicht für eine endgültige Deponieabdeckung oder als temporäre Abdeckung während des MBA-Prozesses.

Diese Arbeit zeigt, wie man durch das Studium der Charakterisierung von Abfällen die am besten geeignete MBA-Technologie für kommunale feste Abfälle identifiziert.

Stichwort: Mechanisch-biologische Verfahren, vorbehandelter Abfälle, Eigenschaften der vorbehandelte Abfälle, MBA-Technologie, Luxemburg, Deutschland, Thailand

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List of Abbreviations

kN/m^2	Kilonewton per square meter
DE	Deutschland/Germany
DIN	Deutsches Institut für Normung/German Institute for Standardization
EK	Eiterköpfe
FH	Fridhaff
ha	hectare
HDPE	High-Density Polyethylene
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
LB	Linkenbach
LU	Luxembourg
m/s	meter per second
MBT	Mechanical Biological Treatment
MD	Muertendall
MH	Meisenheim
MS	Mansie
MSW	Municipal solid waste
OECD	Organization for Economic Cooperation and Development
PL	Phitsanulok
RDF	Refuse Derived Fuel
RJ	Rio de Janeiro

SD	Standard deviation
SH	Singhofen
SS	Sao Sebastio
t/m^3	ton per cubic meter
TASi	German Waste Storage Ordinance
TH	Thailand

Chapter 1

Introduction

1.1 Overview

This project was coordinated by University of Trier in Germany, in collaborations with:

- SIDEC, Syndicat Intercommunal pour la gestion des déchets provenant de la région de Diekirch, Ettelbruck et Colmar-Berg (Luxembourg)
- SIGRE, Syndicat intercommunal pour la collecte, l'évacuation et l'élimination des ordures provenant de la region de Grevenmacher, Remich et Echternach (Luxembourg)
- Deponiezweckverband Eiterköpfe (Germany)
- Deponie Linkenbach Landkreis Neuwied (Germany)
- Deponie Singhofen Rhein-Lahn (Germany)
- Municipality of Phitsanulok (Thailand)

and funded by FNR, Fonds National de la Recherche. The project was established as a 3 years PhD research in the domain field of solid waste technology and management.

Mechanical and biological treatment plays a very important role and is practiced in various countries. For instance, the reported MBT plants capacities in 2005 [Steiner, 2005] in European countries were:

- in Italy approximately 9.9 million tons/year
- in Germany approximately 5.5 million tons/year
- in Austria approximately 3 million tons/year
- in Poland approximately 495,000 tons/year
- in France approximately 257,000 tons/year

Including in Luxembourg, MBT plant operates since 2006. In Southeast Asia, MBT operates in Thailand since 2001. MBT is found worldwide even in Brazil.

The requirement to reduce the fraction of biodegradable waste before sending to the landfills was coerced due to the severe impacts of conventional landfills and incineration (soil, air and water resources, ecological and human toxicological damages and a big damage to the national economy). Most of the earlier studies on MBT waste have been conducted in European countries. Few studies have been carried out in developing countries which in relative terms typically have different types of effective waste management policy and worse pollution conditions. The pretreatment plays a major role in the legislation in the course of national implementation of the European Landfill Directive (99/31/EC) [EU, 1999]. The following specific targets of the reduction of biological degradability of municipal waste fractions in landfill were:

- in 2006, biodegradable municipal solid waste going to landfills had to be reduced to 75% of the total amount of the biodegradable municipal waste produced in 1995.
- in 2009, biodegradable municipal solid waste going to landfills must be reduced to 50% of the total amount of the biodegradable municipal waste produced in 1995.
- in 2016, biodegradable municipal solid waste going to landfills must be reduced to 35% of the total amount of the biodegradable municipal waste produced in 1995.

The reductions were based on the statistical data of municipal waste composition in the year 1995.

In addition, MBT technology is as an alternative option to thermal treatment. Germany was the first country which introduced the MBT technology and sets the target of organic waste reduction by 65% already in 2005. Only MBT waste with total organic carbon less than 18% by weight can be landfilled since June 2005.

MBT process could enhance waste stabilization, reductions of leachate quantity and compositions and methane gas production [Binner 2002; Ziehmann et al. 2003; Körner et al. 2006; Fellner 2008]. Moreover, the MBT material should be safe prior to landfilling, inert and stable for the long-term and require a minimum of aftercare. Biodegradable fractions must be greatly mineralized, and soluble harmful substances converted into stable insoluble materials. Nevertheless, MBT material after the pretreatment could not become constant and stable materials in short time or even over a short period of biological treatment, the chemical composition of the waste could change all the time.

The achievements in solid waste reduction and high stabilized waste greatly depends on appropriate treatment system. There is not a single way of one optimal technology for solid waste management which match with every landfills. The most appropriate technology requires an efficient waste management strategy, a good understanding of ones own waste and practice on landfills as well as a good training of operational staff. Therefore, every landfill operators find and develop their own suitable methods to reach a highest efficiency in waste and landfill emissions reductions.

This study compares physical and chemical of the final MBT material's characteristics and properties from Luxembourg, Germany and Thailand with regard to the methods of treatment system. An overview of background information of waste management, waste generation and composition in these three countries is provided, with emphasis on comparing the different technical aspects of the treatment methods, the rather different waste treatment and its outputs.

1.2 Objectives of the study

The objectives of this study are to define and compare the characteristics of the final MBT materials from Luxembourg, Germany and Thailand. The comparison of this study enhances an understanding of characteristics of the MBT material and provide data for the landfill operators. This is to encourage a further optimization in municipal solid waste management recommendations for landfill sites in study areas.

Chapter 2

Literature review

2.1 Mechanical and biological treatment

2.1.1 Definition

Mechanical and biological treatment is the processing or conversion of waste from human settlements with biologically degradable components. The processes usually include a mechanical step to remove the recyclable materials and prepare the waste for a biological treatment. The biological process reduces the degradable organic fraction of waste. Individual stages of treatment combine with the integrated techniques to meet suitable condition of the outputs [Soyez, 2001].

2.1.2 The development of the MBT systems

The development of the pretreatment of MSW system started with the composting of MSW in Germany [Runge and Hofmann, 2008]. The first large-scale facilities for composting mixed MSW in Baden-Baden and Blaubeuren started operating in 1953. The product of composting waste was not accepted to be used in agriculture due to high harmful materials. Before 1970's, all sorts of waste were simply deposed in German landfills. At that time, contaminations of landfills emissions without pretreatment effected soil and water resources. There was the idea to improve the landfills conditions and to make the incineration cleaner. However, people began to realize that landfills did not guarantee a long-term environmental security and therefore developed the demand for a sustainable waste management. Finally, the German government passed the law of Avoidance and Elimination of Waste with the goal to minimize the waste production and to recycle waste and waste deposition under the responsibility of the government.

In the early 1990, the source separation for organic households waste was initiated and produced compost from it. At the same time, pretreatment concepts were carried out by many projects. In 2001, the German government adopted the Technical Instructions for MSW [AbfAbIV, 2001], which requires pretreatment of all waste containing biodegradable prior to landfilling.

In 1999, the European landfill Directive requested the European members implementation of waste reduction in landfills [Runge and Hofmann, 2008]. Different member states in European countries are free to achieve the goals of the European Landfill Directive (99/31/EC) [EU, 1999].

Since 2001, MBT technology is an accepted alternative treatment to incinerator. The German Waste Storage Ordinance (TASi) has set the policy prohibiting landfilling of mixed municipal solid waste without pretreatment. Between 2001 – 2005, a large number of MBT facilities and incinerators started their operations. The largest MBT plant in Germany, situated in Cröbern near Leipzig. There are in total 66 MBT plants and 73 incinerators in Germany [UBA, 2006].

2.1.3 Concepts of the pretreatment

Mechanical treatment

Mechanical treatment allows the removal of valuable fractions by separation the biodegradable waste from non-biodegradable waste such as plastics, paper and metals, including the preparation for the biological process prior to landfill. In general, the following steps are important parts of the mechanical treatment stage:

- sortation
- shredding/cutting
- size-screening
- homogenization

The homogenization of the MBT is a necessary precondition for a successful biological treatment. In most cases, mechanical treatment is implemented by shredding or comminution. This way the surface area of the waste is increased. The material is customized for the micro-organisms. If it is necessary, the water content can be adjusted.

There are different ways to intergrade such as sortation and screening in the mechanical pretreatment process. The separation of a high calorific fraction (paper and plastics) to be used as refuse derived fuel can be achieved by sieving the waste using screen size between 40 and 100 mm. The rest of organic matter accumulates with the mesh size between $0 - 10$ mm can be separated for composting process.

Mechanical treatment may also means to remove contaminates in the waste. This is most often a manual operation, performed by some kind of manual sorting or manual picking equipment, depending on the waste heterogeneity and the chosen subsequent biological process.

Biological treatment

The bio-degradation of waste is most important for the biological process. The biological process can be subdivided in two sections:

- *Aerobic or rotting process*: in general, waste which contains a high percentage of bulky material, is suitable for a rotting process. At the beginning of rotting process in an aerobic process, the waste which contains organic substances react with oxygen and are converted by micro-organisms (aerobic thermophilic micro-organisms) which prefers an ambient temperature approximately 50 – 55 °C and a water content of around 50%. The waste heats itself up, the energy is released by the activity of micro-organism. Carbon dioxide, water and residues of minerals are the products.

  The stage of hygiene starts when the temperature in the waste is up to 80 °C but when the temperature becomes lower, it stays hygienic. The duration of the rotting process depends on the type of waste, a long rotting duration is needed for not easily degraded materials.

- *Anaerobic or fermentation process*: fermentation process does not need oxygen. Hydrolyses and acidification take place in the first step. In the second step of anaerobic processes, acetic acid and methane are produced. Because the supply of atmospherical oxygen decelerates or even stops the degradation of organic substances by anaerobic micro-organisms. A closed installation is necessary for a fermentation [Clausen, 2007]. An anaerobic process produces biogas (mainly methane which can be used for energy production).

2.1.4 Principles of the MBT technology

Figure 2.1 shows the schematic diagram of concept of MBT operation. There are 4 main basic processes of mechanical-biological treatment:

1. Waste Input and Control
2. Mechanical Treatment
3. Biological Treatment
4. Disposal on landfill

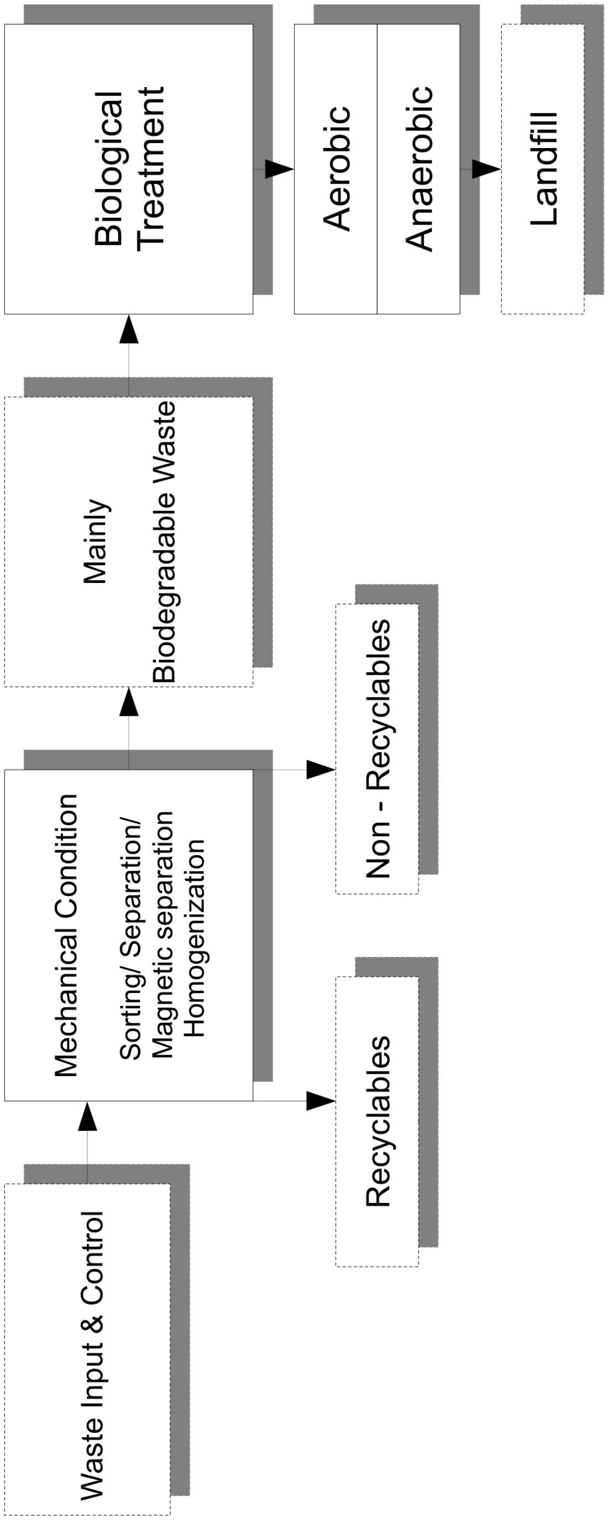

Figure 2.1: Conceptual diagram of Mechanical and Biological Treatment

Waste Input and Control

The incoming waste is first weighed at the designed receiving points:

- The outside receiving point is not expensive and not complex, waste is delivered directly into a landfill. The further steps of shredding and cutting can take place immediately.
- The delivery hall is used for the meaning of reducing smells but complex and expensive.

Mechanical Treatment

Initial inspection of inputs, large objects are rejected and removed in order to prevent the down stream of processes. Household waste contains large amounts of biodegradable materials. It is suitable for the MBT treatment, industrial waste contains polluted materials which are unsuitable materials for the MBT treatment [Clausen, 2007].

Waste is delivered to the machine for cutting and adjusting its particle size. Most of mechanical sorting is done in trommel screening or screening drum. Screening drum has many different sizes of holes which can be used with a waste fraction base on the particle size. The screened residual waste can be further put to the crusher and then turn to another screening drum. If the waste contains a lot of metals, magnets can be used to extract them. Homogenization is the last step of mechanical condition. It can be described as a mixer. Pre-treated waste is mixed into an uniform blending (at this step leachate can be added in order to optimize the moisture content).

Manual sorting by humans is possible to separate large size of plastic sheets, paper, metals and recyclable materials. The manual sorting can also be done at the landfill. The waste is optimally prepared for the biological waste treatment process. The purpose of the biological treatment is to break down the organic substances before the waste is placed at a landfill.

Biological Treatment

The aerobic process was proved to be a more effective biological treatment for the MBT than the anaerobic process [Clausen, 2007]. Various methods to implement the aerobic biological treatment are following:

- Non-mobile composting heap:

  it is one of the most effective methods and is called the chimney aeration method. Composting heap requires the continuous supply of oxygen and constant moisture level. This process is carried out directly at the landfill site. Figure 2.2 presents an aerobic composting windrow. In theory, windrow is a technique designed for increasing the waste degradation potential. The base is prepared with alternative pallets. The waste can be dumped directly around the pipe until it gets around 3 – 4 meters. This simple non-mobile outdoor composting process takes long period like about 12 months [GTZ, 2007].

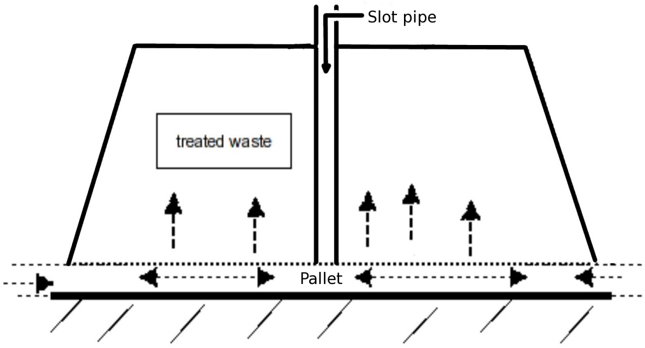

Figure 2.2: Schematic diagram of an aerobic composting windrow

- Semi-mobile composting heap:

  the heap of waste is triangle in shape. The oxygen is provided for the composting heap by turning it regularly. This task is performed using the equipment, the proper moisture is added during the time of turning [GTZ, 2007].

- Mobile composting or intensive composting heap:

  indoor composting heap is designed in 4 meters height. The length and width depend on the base and the nature of the turning equipment. The optimal water content is maintained by regularly adding water as much as required for the process. This kind of composting requires operational expensive equipments.
  This is considered the most expensive process, and therefore it is most suitable for handling the large amounts of waste. Oxygen is added from the base below [GTZ, 2007]. Natural odors from the decomposition process are collected, scrubbed and neutralized by biological filters, (shredded barks is the most common employed filling material). The optimal mobile composting process takes only about 12 weeks.

Disposal on a landfill

The traditional practice at the end of the biological treatment, is to do re-screening of pre-treated waste. The waste is carried out and loaded to the drum screening directly at the landfill. The waste after treatment is separated into two streams: coarse fraction and fine fraction, depending on further utilization. Generally, coarse fraction can be placed at the landfill. Fine fraction can be used for the biological filter material for new heaps. The whole final product can be placed on the landfill and is compacted. First it is spread in a thin layer and then compacted by a compressor.
The mechanical-biological treatment is designed to use the properties of the pre-treated waste, the use of the compactor is not always necessary [GTZ, 2007].

2.1.5 The advantages of the MBT technology

The appropriate techniques and operation can bring the following advantages:

- Reduction of the volume of waste which has to be disposed [Heerenklage and Stegmann, 1995]. The mass of waste after pretreatment can be reduced 50 – 65% by weight. Thailand presented 64% of waste reduction by weight [Tungtakanpoung, 2006]. Linkenbach MBT plant in Germany reduced 65% by weight. Fridhaff MBT plant in Luxembourg reduced 50% by weight.
- Augmented compaction rate on given MBT landfill [Stegmann et al., 1999], compared to a normal landfill. Compacted density of MBT waste is between 0.7 – 1.0 t/m^3 [Barone, 2008]. German landfill is found to be 1.5 t/m^3 of a maximum compacted density on landfill. Austrian landfill found that MBT waste had a compaction density of 1.3 t/m^3 which had saved 30 to 50 % of landfill volume.
- Turk [1997]; Collins. et al. [1997]; Fricke and Friedich [1998] reported reductions of leachate and methane. Low Biological Oxygen Demand (BOD) was also noted. Gas production is less than 10 – 45 L/Kg dry mass [Münnich et al., 2005].
- Reduce the water permeability on landfill. The MBT particles 60 – 80 mm in diameter with an optimal water content showed the permeability value at 10^{-9} m/s [Beaven and Powrie, 1995]. Bidlingmaier and Scheelhaase [1997]; Soyez [2001] and Xie [2003] reported that the values of materials can be in the ranges of 10^{-7} – 10^{-9} m/s . Untreated waste showed the permeability value at about 10^{-3} – 10^{-4} m/s [Beaven and Powrie, 1995].
- Scheffold [1992]; Leikam and Stegmann [1998]; Müller and Fricke [1993] noted that the shear strength of the MBT waste is higher after compaction.
- The biogas which is generated during the fermentation process, can be used as energy supply for the treatment plant (e.g. to heat up the waste) or as current, generated in a block heat and power plant, which can be fed into the communal power line [Clausen, 2007].

2.1.6 The limitations of the MBT technology

Aerobic biological composting process of low cost technology takes long duration. The implementation requires also a lot of space for the country where a large area is not available [Clausen, 2007].

Plants of mechanical-biological treatment have faced with some inconvenient situations as follows [Kühle-Weidemeier et al., 2007]:

Mechanical treatment

- Congestions due to ribbons, deadlocks / standstill / damages by contraries
- High wear, change of the degree of crushing and screen cut due to wear

Biological treatment

- High cleaning effort, particularly for ventilation
- Wear, e.g. moving (walking) floor
- Limited potentiality for hall ventilation
- Release of ammonia gas, anaerobic zones in the composting

Waste Storage Ordinance IV [AbfAblV, 2001] requires the material characteristics of the mechanical-biological treated wastes as described in Table 2.1.

Table 2.1: Material characteristics of MBT materials according to AbfAbIV cited in [Münnich et al., 2005]

Parameter	Allocation criteria and unit
Size per piece	approximately $<$ 40 to 60 mm
Water content	35% in fresh mass, 28 to 40% in dry mass
Loss of ignition	approximately $<$ 31% dry mass
Mineral content	approximately $>$ 69% dry mass
Residual gas potential	$<$ 10 to 45 Nm^3/ M_g dry mass

Selection of the allocation criteria for the deposition of mechanical-biological treated waste in Germany since June 2005 is shown in Table 2.2. The respiration index is a value of microbiological oxygen consumption in 4 days, related to the amount of substrate. The gas formation potential is the analysis of biogas formation of the waste sample in 21 days [Körner et al., 2006]. TOC (eluate) by standard procedure (1:10 solid/liquid ration and 24 hours shaking).

Table 2.2: Allocation criteria and unit for MBT material according to AbfAbIV cited in [Körner et al., 2006]

Parameter	Allocation criteria and unit
Respiration Index (RI_4)	10 mg O_2/g dry mass
Gas formation potential (GB_{21})	20 N ml/g dry mass
TOC (eluate)	250 mg/l
TOC (solid)	$\leq$ 18 % by mass
Gross calorific value	$\leq$ 6000 kJ/kg

In addition, excavated gas emission target values from in-house treatment facilities (waste delivery, mechanical and biological treatment) have also been set in Table 2.3.

Table 2.3: German target values for gas emission according to AbfAbIV cited in [Körner et al., 2006]

Parameter	Allocation criteria and unit
Total organic carbon (TOC)	20/40 mg/ mg^3
TOC	55 g/Mg
Dust	10/30 mg/ mg^3
Odour	500 OU/ m^3
PCDD/F	0.1 ng/ m^3
Nitrogen dioxide (N_2O)	100 g/Mg

2.2 MBT materials characteristics

Mechanical-biological pretreatment changes fundamentally the physical, chemical and biological properties of municipal waste to be landfilled compared with the waste which is landfilled without pretreatment [Xie, 2003]; [Körner et al., 2006]. Emission potentials are reduced as well as waste mass volume after the pretreatment process (50% by weight [SIDEC, 2006], and 64% by weight [Tungtakanpoung, 2006]). The changed structure of MBT waste has consequences on the physical properties such as particle size and hydraulic behavior [Barone, 2008]. These two properties are related and influencing each other.

Physical transformations change waste in volume and size. Chemical transformations involve a change of phase (e.g., solid to liquid, solid to gas). Biological transformations involve a change of organic waste that is decomposed by bacteria, fungi, yeast, and actinomycetes. These transformations may be achieved either aerobically or anaerobically, depending on the availability of oxygen. Aerobic conversion transforms waste to composting, while anaerobic conversion transforms waste to CO_2 and CH_4 and resistant organic matter [Tchobanoglous et al., 1993].

2.2.1 Physical characteristics

Physical characteristic of MBT waste is studied by various authors. Physical tests such as particle size distribution, permeability, emplacement density, settlement and shear strength of MBT materials were extensively studied by Bidlingmaier and Scheelhaase [1997]; Xie [2003]; Bauer et al. [2007]; Münnich et al. [2005]. Particle size distribution, density, water content by Leikam and Stegmann [1996]; Tungtakanpoung [2006], and etc. Leaching tests by Münnich et al. [2001]; Binner [2002]; Ziehmann et al. [2003]; Warnstedt [2005]. Toxicity and heat value of MBT waste by Tungtakanpoung [2006].

Particle sizes:

The size of MBT waste is significantly smaller than fresh waste. Smaller particle sizes provide greater surface areas and thus more rapid reaction with micro-organisms in a compost pile, or more rapid combustion in an incinerator [Pichtel, 2005]. MBT waste is visibly similar to soil materials. MBT waste exhibits a higher homogeneity in comparison to untreated waste [Bauer et al., 2007]. The prescriptive limits according to AbfAbIV requires a sieving particle sizes of MBT waste smaller than 40 to 60 mm cited in [Münnich et al., 2005] see Table 2.1. Through the intensive mechanical treatment of MBT process, the properties of municipal solid waste are changed in term of maximum size reduction and thus supporting the bio-degradation process in landfills. A study at Wilhelmshaven landfill in Germany has shown that the MBT sample which was treated by a chimney effect system showed 60 – 70% by weight of fine fractions < 30 mm and about 15% by weight of coarse fractions > 70 mm of the whole sample [Koelsch and Reynolds, 1999].

Emplacement density and settlement:

Smaller particle sizes lead to higher emplacement density. The emplacement density depends on the consumed compaction energy and the water content which has to be not higher than 35% wet mass [Münnich et al., 2005]. Results of studies indicated that the emplacement density is often determined in advance with the geo-technical proctor test. The proctor densities for aerobically stabilized wastes are in the range of 0.70 to 1.20 t/m^3 dry matter. Materials from anaerobic treatment showed lower value ranges. The densities which were measured on test fields by means of volume replace method were up to 25% over the proctor densities determined in a laboratory test [Bauer et al., 2006]. Result of a test showed that settlement values of pre-treated waste less than 40% compared with old untreated waste at a similar vertical charge. A good compaction of waste at emplacement definitely influences the height of future settlements. A low emplacement densities can be improved afterwards only slightly by high surcharges. A maximum possible settlement respectively volume reduction of approximately 4.5% is resulting from the degradation of organic matter [Fricke and Friedich, 1998].

Shear Strength:

Strength characteristic of MBT waste differs from soil material. The shear strength of MBT waste is caused predominantly by two shear resistance elements, friction and fibrous cohesion. Direct shear tests with smaller device (shear surface 30 x 30 mm) showed the result that smaller components of waste cause the main part of the internal friction. The increase of the reinforcing effect with increasing load is described by the internal angle of tensile stress; a maximum reinforcing stress of 225 kN/m^2 results in case of 300 kN/m^2. The cohesion was not influenced by the varying treatment and amounted to approximately 15 kN/m^2. The stability of landfill body will be reduced by the emplacement of fine particle waste components. The amount of reinforcing elements bearing tensile stress is reduced, therefore followed by a decrease of stability of landfill body [Bauer et al., 2006] and [Münnich et al., 2005]. The wastes should be emplaced on the landfill surface with a gradient of 5 – 10%.

Hydraulic behavior:

Many authors and numbers of researches studied the saturated hydraulic conductivity of MBT waste. In fact, saturation, de-saturation and infiltration regularly happens in landfill body. Saturated hydraulic conductivity values of MBT waste range from 10^{-6} to 10^{-9} m/s [Münnich et al., 2005]. Untreated wastes range from 10^{-3} to 10^{-6} m/s. This physical property strongly influences the movement of liquids (especially leachate) and gases in a landfill. Smaller particle sizes of MBT waste will not induce a reduction of the hydraulic conductivity. This is because of the coarser particle sizes have an increasing portion of plate or plane shaped components for example foils which at a stratified layer emplacement are leading to a massive disability of the verticle water movements. Vertical hydraulic conductivity of MBT waste is usually determined in laboratory by triaxial tests. Results of anisotropy of MBT waste compared with fresh waste is distinctly reduced but coarser particle size of foils can explicitly affect the flow behavior of leachate [Bauer et al., 2006].

Table 2.4 shows the classification of soils according to their coefficients of permeability Kulhawy and Mayne [1990].

Table 2.4: Classification of soils according to permeability [Kulhawy and Mayne, 1990]

Degree of permeability	Value of k (cm/sec)	Soil
High	Over 10^{-1}	Gravel
Medium	10^{-1} – 10^{-3}	Sandy gravel, clean sand, fine sand
Low	10^{-3} – 10^{-5}	Sand, dirty sand, silty sand
Very low	10^{-5} – 10^{-7}	Silt, silty clay
Practically impermeable	less than 10^{-7}	Clay

Water transportation:

MBT wastes are assemblages of porous solid particles with interconnected voids through which water can flow from a point of high energy to a point of low energy. Pore in these materials are filled with water and/or air. Generally water between the porous media is divided in dependent on the kind of connection to the solid waste. The amount of water which is kept adhesively against the gravity is called retained water [Hölting, 1989].

The retained water could be divided further in capillary water and adsorption water. The capillary water exists because of the capillary forces on top of the groundwater surface in the capillary water edge and is divided further into closed and open capillary water edge (DIN 4049-3). The adsorption water is the part of the retained water, which is absorbed as water film on the surface of the mineral particles of the porous media.

Water (e.g. precipitation) which infiltrates the waste and moves downward due to the gravity (as far as its not groundwater) is called leachate. During the leaching process, a part of the retaining water is swamped out by leachate and is moved downwards by itself. Water does not flow from point A to point B in a straight line at constant velocity but rather in a winding path from pore to pore. Porous MBT waste is important. It determines the rate at which water flows through material, the rate of settlement of a foundation and the strength of the material. Water or permeant in MBT waste with compacted density always flow with a low rate and most of the pollutants remain in place due to small sizes of organic waste composition [Vaidya, 2002].

Water retention capacity:

The amount of water by weight or volumetric basis expressed as percentage of waste beyond its holding capacity. Water-holding capacity of a material depends on its type, organic matter content, and past management practices, among other things. Evaporation at the solid surface pulls water upward through capillary forces, while capillary forces also hold water around the soil particles. When a balance is reached between gravitational and capillary force, water stops moving downward and is held by surface tension in the soil – a condition known as field capacity [Vaidya, 2002]. Typically field capacity of municipal waste range from 14 to 44%. The capacity of MBT waste in water storage differs from other materials. Higher void spaces in smaller particle sizes of MBT waste leads to high water retention capacity [Münnich et al., 2005].

Water content:

Water content in waste is an important key in controlling the progress and rate of biodegradation. Micro-organism needs water and oxygen for an effective degradation. An open - aerobic composting need less water during rainy season. An optimal water content inside a windrow or a heap is often given as about 30 – 35% wet mass [Münnich et al., 2005].

If the water content differs too much from the optimal one, the biological, thermophillic process ceases. If the rotting process is not continuous, the potential bio-degradation may be decreased. Constant water level is required for the biological treatment. High water amount is needed for an anaerobic composting process. Due to lacking of oxygen condition, organic matter reacts to the water. In the first step of the fermentation, hydrolyses and acidification take place. In the second step acetic acid and afterwards methane are produced. An aerobic composting process, organic matter reacts to the oxygen then water is released into the air together with carbon dioxide and other minerals. An aerobic composting process is proved to be the most suitable biological treatment for the MBT. The outputs show much reduced water content in material. Due to its low water content, the material can be stored over long periods. Beside, the reduced water content of input material for the landfill means reduced amount of leachate which occurs in the landfill over the time [Clausen, 2007].

2.2.2 Chemical characteristics

The change of phase from solid to liquid or solid to gas by micro-organism activity is called chemical transformation. Chemical properties of MBT waste are positively changed by the pretreatment compared with untreated waste. The chemical properties of waste are often determined from its emission potential, leachate quantity, quality and gas production. A number of researches have proved that amounts of leachate and methane are reduced more than 98% compared with untreated waste. One kilogram of MBT waste potentially releases a total load of 1– 3 g COD (chemical oxygen demand), 0.5 – 1.5 g TOC (total organic carbon), and 0.1– 0.2 g $NH_4 - N$ (ammonium-nitrogen) into the leachate [Soyez, 2001].

The respiration activity is measured by the (AT_4), total organic content and the gas formation within 21 days (GB_{21}) methods. Amongst these 3 methods, the AT_4 is the most easily determined and the time for an analysis is short enough for technical purposes. The respiration rate AT_4 is defined as the amount of oxygen consumed by microbial processes. Typical values of the AT_4 are in the range of 30 to 50 mg O_2/g dry matter for untreated material. In contrast this values of the MBT waste range between 1.1 – 7.4 mg O_2/g dry matter [Pichler, 1999]. Concentration of heavy metals are reduced significantly from leachate analysis. Although the pre-treatment reduces great amounts of emissions, landfill emissions will still occur. Therefore disposal limit values for the MBT waste were set up (Tables 2.1, 2.2 and 2.3).

The chemical characteristics of MBT waste are changed by pretreatment compared with untreated waste. The Table 2.5 presents the range of organic carbon, nitrogen and chlorine transfer by gas and leachate; minimum values represent the stabilization degree.

Table 2.5: Chemical characteristics of untreated waste and MBT waste [Soyez, 2001]

Emission potential	Unit	Untreated waste	MBT waste
Gas			
Carbon	l/kg dry mass (DM)	134 – 233	12 – 50
	g C/kg DM	71.7 – 124.7	6.4 – 26.8
Leachate			
TOC	g/kg DM	8 – 16	0.3 – 3.3
N	g/kg DM	4 – 6	0.6 – 2.4
Cl	g/kg DM	4 – 5	4 – 6

2.2.3 Leachate characteristics

Leachate is a high strength wastewater characterized by high concentrations of organics and ammonia and potentially containing toxic levels of heavy metals [Engelhardt, 2006]. Leachate volumes will be formed in each case, depending on the physical properties of the emplaced waste (e.g. material grain size, emplacement density, infiltration rate) and the intensity of precipitation [Münnich et al., 2005]. Little open emplacement areas, high emplacement densities, smooth and inclined surfaces induce a distinct reduction of the leachate volume.

Organic constituents, ammonia, and heavy metals in leachate are the three primary treatment and disposal issues, in addition to high total dissolved solids concentrations. Organic constituents are typically characterized in terms of chemical oxygen demand (COD), 5 – day biological oxygen demand (BOD_5), and total organic carbon (TOC). Generally, high COD (3,000 – 60,000 mg/L) and high BOD_5/COD ratio > 0.6 characterize leachate from young landfills ($< 1 - 2$ years old), and in contrast, relatively low COD (100 – 500 mg/L) and low BOD_5/COD ratio < 0.3 characterize mature leachate from landfills more than 10 years old [Tchobanoglous and Kreith, 2002].

Figure 2.3 illustrates the biodegradation in landfill which occurs in sequences until reaching the end products. In each step of biodegradation is subdivided into 5 continuous phases by its predominant products in landfill leachate quality [Chiemchaisri et al., 2004].

Phase I : Initial adjustment phase

When solid waste is sent to a landfill, it takes water and air concomitant with it. Thus, predominant product is organic matter, dominated gas is still being N_2 and O_2. Biological decomposition occurs under aerobic condition that results in elevation of CO_2 concentration.

Phase II : Acid phase

The continuous solubilization (hydrolysis) of solid waste, followed by the microbial conversion of biodegradable organic content, results in the production of VFA and COD at high concentration. The pH value can be observed at the lowest value from the other phase.

Phase III : Transition phase

Transition phase means shifting in aerobic to anaerobic environment. Oxygen is depleted by microorganism respiration (utilization). Results of anaerobic condition are COD (chemical oxygen demand), VFA (volatile fatty acids) and CO_2. The pH of leachate is decreasing due to the presence of VFA and CO_2 solution. The low pH mobilizes heavy metal from the waste into the leachate.

Phase IV : Methane fermentation phase

The conversion of VFA and H_2 gas to CH_4 and CO_2 is a predominant event due to strict anaerobes. The utilization of organic acids supports the elevation of pH value. Organic contents in leachate transform to CH_4 and CO_2 gas, which make COD, SO_4, and Cl decrease significantly. Heavy metals those presence in the leachate tend to decrease because of high pH value that creates complexation and precipitation and transport to solid phase.

Phase V : Maturation phase

Easily biodegradable waste is decomposed to leachate and landfill gas already. The landfill has remaining of refractory biodegradable that hardly decomposed in anaerobic condition. Thus, gas production drops and leachate strength stays behind constant level.

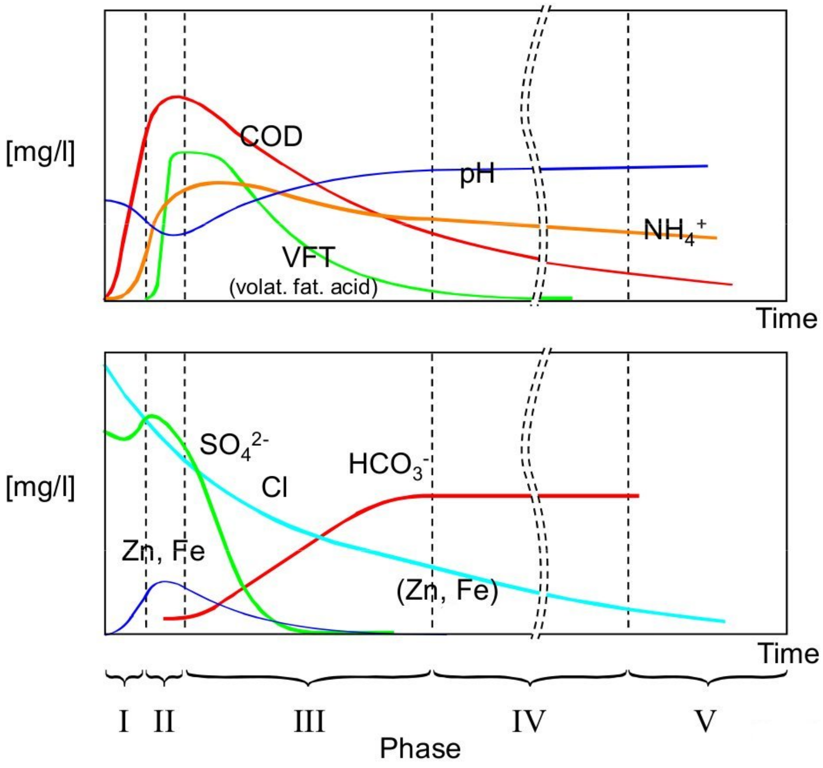

Figure 2.3: Leachate emissions from landfill [Data source: Tchobanoglous et al., 1993]

Pretreatment changes leachate characteristics to be a great reduction of generation and composition. As well as the pollutant concentrations in leachate are much lower compared with untreated waste. Result of Chemical Oxygen Demand (COD) and Total Kjeldahl Nitrogen (TKN) load (mg/L) are reduced up to 90% based on an average initial leachate concentration [Körner et al., 2006].

A comparison of leachate emissions of MBT landfill with MSW landfill and Bottom ash landfill is shown in Table 2.6. It can be seen that the pH value of leachate in MSW landfill is lower than the pH value of leachate in MBT landfill and Bottom ash landfill. The COD and NH_4 concentrations of MBT landfill are much reduced but chloride and sulfate did even slightly increase compared to MSW landfill.

Table 2.6: Comparison of leachate emissions [Fellner, 2008]

Parameter	Unit	MSW landfill		MBT landfill		Bottom ash landfill	
		Min.	Max.	Min.	Max.	Min.	Max.
pH	mg/L	3.5	9	6.4	8.4	8	11
COD	mg/L	500	60000	400	8300	34	500
NH_4	mg/L	20	3000	<0.1	1000	20	50
Cl^-	mg/L	100	15000	800	16000	2400	19600
SO_4^{2-}	mg/L	50	3000	50	10500	70	5800
Pb	mg/L	0.02	1	<0.005	1,60	<0.0005	0.04

Table 2.7 presents results of physical and chemical characteristics of MBT waste by various authors in different countries. It can be seen that water contents of the MBT waste from Thailand and Brazil are higher than the MBT waste from Germany. The pH value of all MBT sample are very similar. The concentrations of Lead, Cadmium and Arsenic in leachate of MBT material are very low.

Table 2.7: Physical and chemical characteristics of MBT waste in different countries

Parameter	Unit	Germany			Thailand	Brazil	
		MH	LB	MS	PL	SS	RJ
Disposed period		9 weeks	10 weeks	7 months	12 months	9 months	12 months
Solid waste test							
Total solid	mg/g	-	-	-	786	-	-
Water content	%	25	78.5	31	60	> 60	-
Loss of ignition	%	-	29.6	-	18	-	35
Respiration rate	mg/g	-	1.64	-	2	2.6	1.7
Fermentation rate	Nl/kg	-	5	-	-	-	1.8
Density dry	t/m^3	0.97	-	0.91	0.76	-	-
Leaching test							
pH-value	(-)	6.4-8.0	7.03	7.5	7.98	7.1	7.6
EC	µ S/cm	4,580-12,110	-	3710	-	785	619
COD	mg/L	414-1,064	-	452	-	300	243
TOC	mg/L	-	97	98	160	92	82
NH_4-N	mg/L	1.2-9.1	-	< 5	9	-	< 5.0
Pb	mg/L	< 0.1-0.6	-	-	0.32	-	< 0.10
Cd	mg/L	< 0.1	-	-	< 0.003	-	< 0.10
As	mg/L	-	-	-	0.26	-	< 0.025
Source of data		Ziehmann et al. 2003	Xie 2003	Ziehmann et al. 2003	Körner et al. 2006	[GTZ, 2007] 2007	Münnich et al. 2001

2.3 Demography and Waste management system

2.3.1 Luxembourg

Demography

The country is officially called Grand Duchy of Luxembourg. It is situated in western Europe and covers an area of 2,586 km^2. It is one of the smallest countries in Europe with a population of 462,000 people (2009). It is divided into 118 communities. It is bordered to the east by the German Bundesländer of Rhineland-Palatinate and Saarland, to the south by the French région of Lorraine, to the west by the Belgian Walloon Region, to the north by the German-speaking Community of Belgium [Wikipedia.org, 2009b]. Luxembourg standard of living quality ranks high among countries in western Europe. It is a country with various cultures and a fast growing tertiary sector [Wikipedia.org, 2009b]. Luxembourg city is the capital of the Grand Duchy of Luxembourg and the largest city. It is an industrialized and urbanized city with strong focus on the bank service sectors.

Waste management system

The municipal solid waste management system has been sufficiently supported by the government. Although this country is like many other countries facing an increasing amount of waste due to a rapid economic growth with progress and changes in its social system, the supplying municipal solid waste service is always available. The administration of Environment elaborated a policy to measure the situation of solid waste and environmental controls. Therefore an important aspect of environmental awareness has been recognized. It is called an intergradation of solid waste management and includes reduction, reuse, recycling, incineration and landfilling of solid waste.

One incinerator and two disposal sites are operating as facilities for municipal solid waste treatment of Luxembourg's waste. Regarding the collection and transportation of waste, efficiency of the collectors is well done.

Public waste containers to separate recyclable paper and glass are often available. The plastic (only drinking bottles and soap containers), metal (all metals except aluminium foil) and liquid packaging containers are known as PMG in Luxembourg's recycling collection. The people living in Luxembourg call this collection “Bloen Saack” which translates into English as “blue bag”. These materials are collected in blue bags and are collected from door-to-door once every 2 weeks by the collectors of valorlux.[1] The blue bags and the service are free to Luxemburgish inhabitants. Residual waste is collected by pressing trucks to reduce waste volume before its transportation to the landfill. The country is divided into three areas and is serviced by three syndicates involved with the municipal solid waste management system: SIDEC, SIDOR and SIGRE. Table 2.8 shows the information of the three syndicates for waste disposal.

In addition, Germany is required to keep their national laws with all EU regulations and EU Directives, e.g., European Directive on Packaging and Packaging Waste (1994), European Landfill Directive (1999), and European Waste Incineration Directive (2000).

Table 2.8: The structure of municipal solid waste management in Luxembourg

Syndikaten	Number of communities	Waste Treatment Facilities
SIDEC	57	Fridhaff landfill in Diekirch/Erpeldange
SIDOR	36	Incinerator in Leudelange
SIGRE	25	Muertendall landfill in Flaxweiler

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[1] Valorlux is a suborganisation from Lamesch, which is a firm that collects and recycles waste

Waste generation

Luxembourg

Figure 2.4 illustrates the development of MSW generation over the period 1996 – 2008 in Luxembourg. The total annual generation of MSW has quickly increased from 486 kg/capita in 1996 to 701 kg/capita in 2008, an increase of 30% since 1996 to 2008. In 2006, there was 551 kg/capita of waste generation, and this has rapidly increased by 2007 to 694 kg/capita. That shows an increasing tendency of waste generation in Luxembourg.

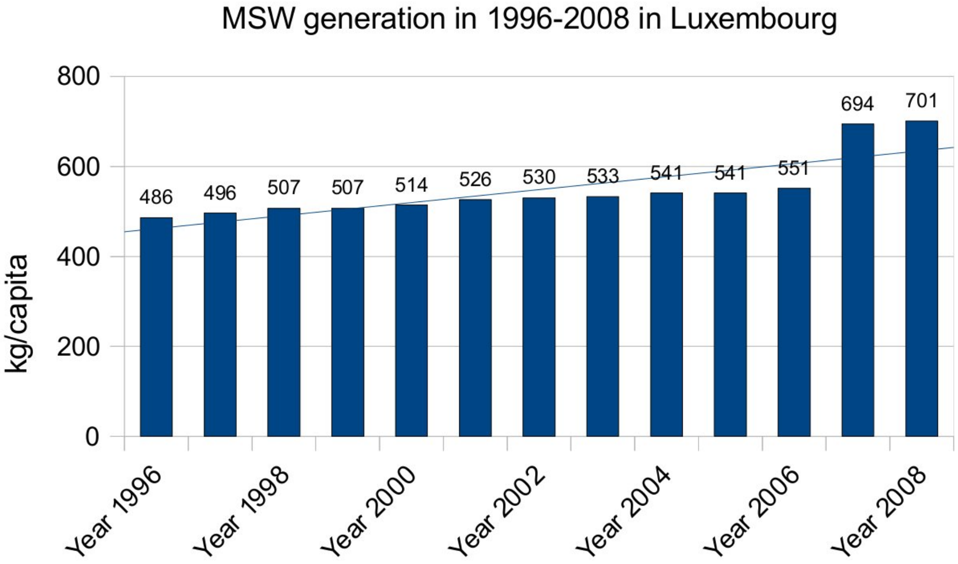

Figure 2.4: MSW generation 1996 – 2008 in Luxembourg. (Data source: OECD, 2009)

2.3.2 Germany

Demography

The country is officially called Federal Republic of Germany. It covers a land area of 357,021 km^2 with a population of 84 million people (2009). The country is divided into 16 states. It is bordered to the north by the North Sea, Denmark, and the Baltic Sea; to the east by Poland and the Czech Republic; to the south by Austria and Switzerland; and to the west by France, Luxembourg, Belgium, and the Netherlands [Wikipedia.org, 2009a].

Waste management system

Waste management in Germany has been developed since the early 1970's. The first Waste Disposal Act aimed to shut down uncontrolled waste dumps and landfills and replace them with regulated and improved landfills under the responsibility of the regional and local government. Later the new Waste Avoidance and Management Act was introduced in 1986. The principal aimed to avoid waste and to do more recycling instead of creating new landfill sites and incineration plants.

According to BMU (2009), a series of legislation, ordinances, administrative provisions and voluntary commitments of waste management has been put in place. For examples:

- Technical Instructions on the Storage, Chemical, Physical and Biological Treatment, Incineration and Storage of Waste Requiring Particular Supervision in 1991.
- German Packaging Ordinance in 1991.
- Technical Instructions on Waste from Human Settlement in 1993. (TASi)
- Act for Promoting Closed Substance Cycle Waste Management and Ensuring Environmentally Compatible Waste Disposal in 1994.
- Closed Substance Cycle and Waste Management Act in 1996.
- Waste Storage Ordinance in 2001.

As Luxembourg, Germany is also required to keep their national laws with all EU regulations and EU Directives.

The source separation system of organic waste is practiced in Germany since the early 1990's. The "brown bin" dedicated in collection of source separated organic waste from households and "yellow bag" is used for recyclables waste collection. Nearly half of all German households use the brown bin system for source separation of organics, capturing about 35 – 50% of all waste generated in these households, or about 9 million tons of source separated organic waste annually. There are about 800 composting facilities in Germany with a total input capacity of nearly 10 million tons of organic waste per year. Those facilities take part in the quality assurance system of the German Composting Association, producing 5 million tons of high quality compost annually [Runge and Hofmann, 2008]. The mixed household waste which contains foods and packages is collected in the grey bin and these waste ends up at the MBT plants. The MBT plants receive approximately 25% of the total municipal waste collected in Germany with capacity of about 6 million tons/year [UBA, 2006].

Waste generation

Figure 2.5 shows data for MSW generation from 1996 to 2008 in Germany. The waste generation showed an increasing tendency from 399 kg/capita to 581 kg/capita in 2008 over the same period, compared to Luxembourg. The percentage of an increase over the same period is similar. However, the number of waste generation is smaller than that one in Luxembourg. The graphical data shows a declined remark of waste generation during 2000 – 2006. In 2006, the waste generation showed an increasing tendency again.

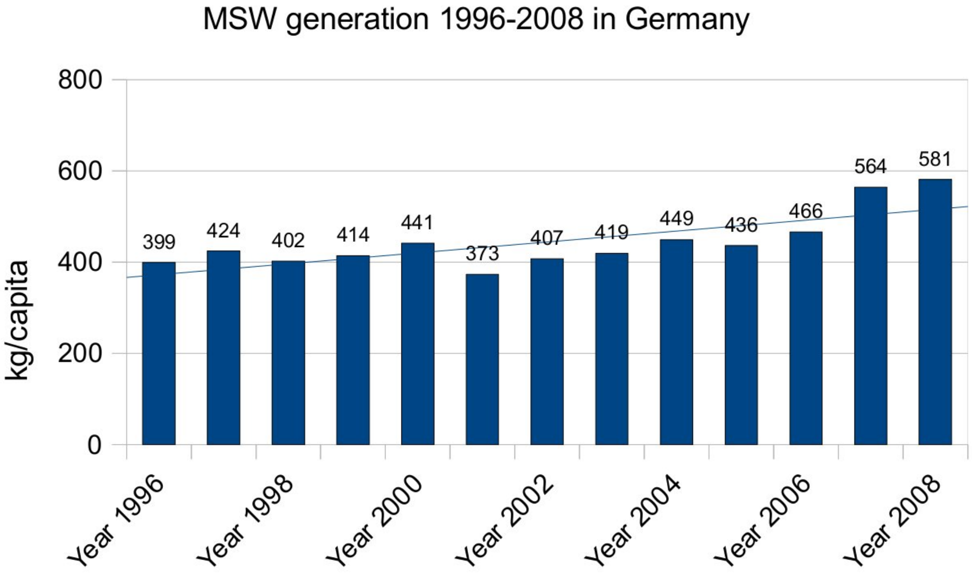

Figure 2.5: MSW generation 1996 – 2008 in Germany. (Data source: OECD, 2009)

2.3.3 Thailand

Demography

The country is officially called Kingdom of Thailand. It is a stable and prosperous nation with abundant resources. It is situated in the heart of Southeast Asia with an area of 513,115.02 km^2. The population is 65 million people (2009). The country is divided into 76 provinces [Wikipedia.org, 2009c]. It is bordered to the north by Burma and Laos, to the east by Laos and Cambodia, to the south by the Gulf of Thailand and Malaysia, and to the west by the Andaman Sea and the southern extremity of Burma.

Waste management system

Municipal solid waste management in Thailand is insufficient in term of policy, source separation, waste collection and treatment. The original solid waste management's law in Thailand was in the Public Health Law of 1941, which defined the authority and responsibilities of local governments concerning waste management. However, this law was insufficient to cope with the increased amounts and complex features of waste in the 1980's.

In the mid 1980's, the first legislation to plan for MSW management was enacted. During in 1991 – 1996, new policies of polluter pays principle, promoting recycling, exploitation of the private sector, management of toxic wastes and waste reduction plans were proclaimed in the National Economic Development Plan.

In the 1990's, Thai legislation changed to focus on decentralization and deregulation. With decentralization policy, the new Constitution of 1997 extended basic civil rights to include environmental issues. The smaller administrative units are called the Tambon Administrative Organization (TAO) became self-governing bodies. Both TAO and municipalities have authority and responsibilities for their own waste and environmental management. Most of the time, those administrative system have to deal with MSW with less experience, skills and insufficient equipment without financial supporting from government.

On source separation front, both central and local governments have increased source separation to reduce the amount of waste. Nevertheless, good practices are limited for a success at the local communities and schools. In addition, traditional waste pickers who collect recyclable waste from waste bins or households, are practically accepted by the Thai society. At present, source separation for organic waste with recycling behavior is difficult to implement in Thai households. The MSW is collected using the waste bin located along the street. Three colored waste bin are used for distinguishing from dry waste to wet waste and recyclable waste. People participate less in such waste separation campaign. People usually sell their recycle waste to Saleng[2] who visits each household, and the rest of the waste are discharged at the waste bin provided by municipality. Residential solid waste is currently collected by municipality and charged at a fixed rate of fee per household in Thailand. MSW in Thailand is mostly landfilled. Thailand has 425 disposal sites (95 landfills; 330 open dumps) and 3 incinerators [Chiemchaisri et al., 2008]. 3 incinerators are operating mostly for clinical and hospital waste in Thailand [Fujii, 2007].

MSW only in Bangkok is estimated 9,400 tons per day and organic waste is about 61%. The Bangkok Metropolitan Administration (BMA) used to run composting since 1960. The composting plants were shut down because of producing poor quality of compost, inadequate storage space and insufficient marketing facilities [Anonymous, 2005].

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[2] Saleng is the private waste collector who seeks and buys the recyclables and sells them to the junkshop dealers [Fujii, 2006]

Waste generation

Figure 2.6 shows data for MSW generation from 1993 to 2003 in Thailand. The waste generation has increased steadily from 30,000 tons/day in 1993 to 40,000 tons/day in 2003. The total amount of MSW in Thailand reported 14.5 million tons in the year 2007 [Chiemchaisri et al., 2007]. By this 21% generated from Bangkok, 32% from cities around Bangkok and Pattaya and 47% from municipalities [PCD, 2005]. The amount of MSW in Thailand generates approximately 40,000 tons/day [Fujii, 2006]. Thailand's average amount is relatively higher than other Asian nations. Especially, in Bangkok and other local core cities with more than 5% annual increase in the past two decades [Fujii, 2006]. Waste generation rate varies from city to city. A high average waste generation rate is in the regions where tourism flourishes. Larger cities have also higher value than smaller cities.

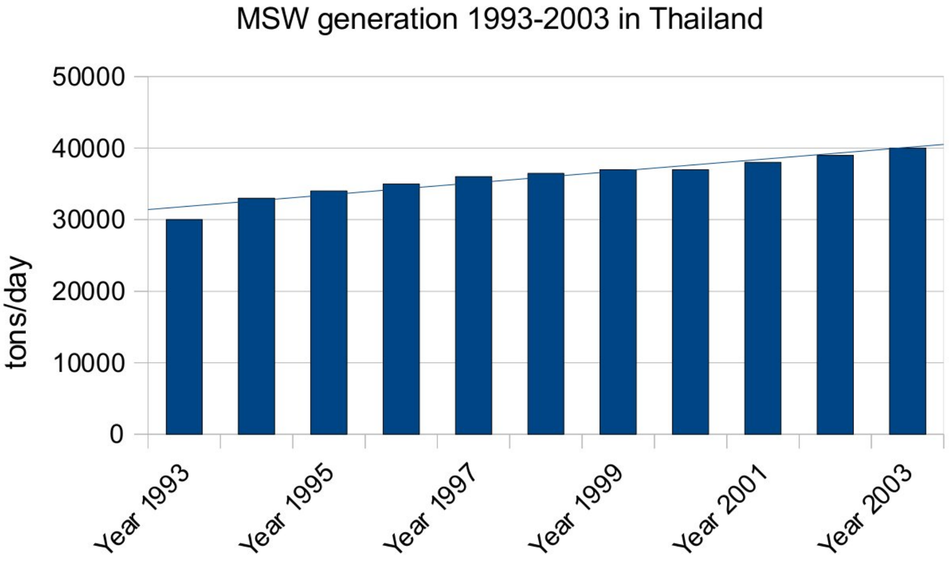

Figure 2.6: MSW generation 1993 – 2003 in Thailand. (Data source: Visvanathan, 2006)

2.4 Waste composition

Figure 2.7 shows the graphical data of comparison of average main municipal solid waste composition focusing the year 2004 for Luxembourg, Germany and Thailand. The sources of data are from different places as follows.

Körner et al. [2006] reported that municipal solid waste of Germany contained of 16% organic waste, 39% paper, 23% plastic, 3% metals and 19 % others. It has to be mentioned that a high amount of MSW is recycled in Germany. By 2007, only 25% of MSW was going to landfill [BMU, 2010].

Schmit [2005] reported that municipal solid waste of Luxembourg contained of 31% organic waste, 24% paper, 18% plastic, 3% metals and 24% others. After this report nearly 50% of the total waste is going to landfill [Schmit and Mathieu, 2005].

AIT [2004] reported that municipal solid waste of Thailand contained of 53% organic waste, 12% paper, 14% plastics, 4% metals and 17% others.

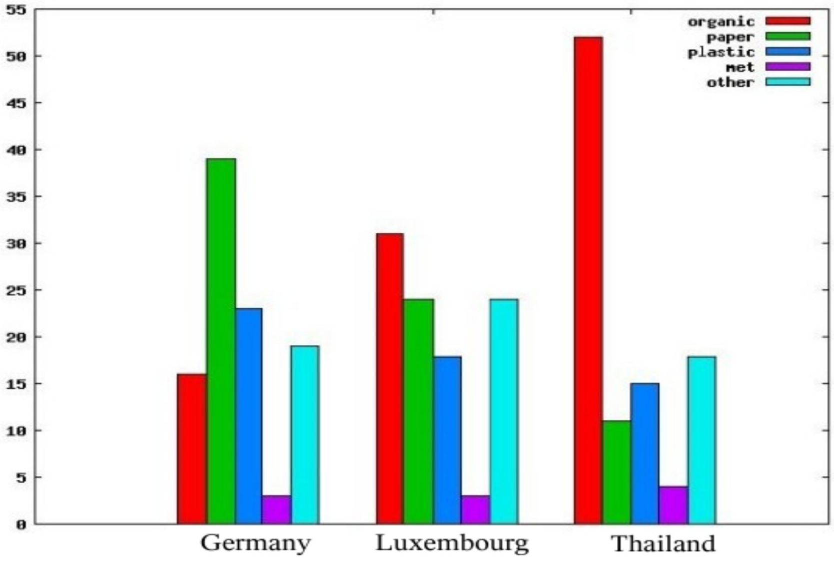

Figure 2.7: Comparison on 5 categories of municipal solid waste composition in 2004 (% by weight) for Germany, Luxembourg, Thailand

It can be said that organic waste in municipal solid waste of Thailand is double higher than Germany and Luxembourg. Thai MSW contains high proportion of food waste and garden waste throughout the year about 40 – 85%. Paper and plastics contents in municipal solid waste of Germany are higher than Luxembourg and Thailand. The percentage of metals in municipal solid waste of three countries is similar. Other waste consisted of the different percentages of inert, textile, rubber and toxic waste.

The type of waste are classified and detailed in the European Waste Catalogue (EWC). The EWC categorizes wastes based on a combination of the type of substances they contain, and the process or activity which produced them. Each waste has a code. An example of Luxembourg MSW is shown in Table 2.9. According to the data, organic, especially kitchen waste is found to be the highest percentage by weight (16.8%) of the MSW in Luxembourg.

The Thai waste has no code but it is suggested by the report to classify waste into 7 categories as shown in Table 2.10.

Table 2.9: European Waste Catalogue for MSW of Luxembourg [Schmit and Mathieu, 2005]

Code	Item	Code	Detail	Weight	
				Kg	% by weight
SG01	Paper/Carton	SF01	Paper/Carton	3505.00	3.45
	PPK	SF02	Print product	7065.80	6.96
		SF03	Other PPK	11805.15	11.62
SG02	Plastics	SF04	Foil	9130.00	8.99
		SF05	Plastic bottle	2156.30	2.12
		SF06	Package	3053.75	3.01
		SF07	Polysterol (EPS)	521.20	0.51
		SF08	Other plastic	2567.30	2.53
SG03	Inert	SF09	Glass package	3459.80	3.41
		SF10	Other inert	1954.40	1.92
SG04	Combination material	SF11	Drink carton	759.70	0.75
		SF12	Shoes	637.30	0.63
		SF13	Electronic	664.40	0.65
		SF14	Other	2101.30	2.07
SG05	Metal	SF15	Fe-metal (package)	1668.85	1.64
		SF16	Fe-metal (non-package)	567.25	0.56
		SF17	Ne-metal (package)	756.10	0.74
		SF18	Ne-metal (non-package)	172.95	0.17
SG06	Organic	SF19	Kitchen waste	17062.75	16.80
		SF20	Garden waste	2992.05	2.95
		SF21	Woods	924.40	0.91
SG07	Napkins	SF22	Napkins	4742.90	4.67
SG08	Textile	SF23	Clothes	2622.50	2.58
SG09	Hazardous waste	SF24	Hazardous waste	938.85	0.92
SG10	Fraction	SF25	$> 0 - 8$ mm	1568.05	1.54
	Fraction	SF26	$> 0 - 40$ mm	10139.90	9.98
SG11	Other	SF27	Other	8023.80	7.90
Total				101561.75	100.00

Table 2.10: Suggested categories of municipal solid waste composition of Thailand [Fujii, 2006]

Item	No.	Detail
Organic waste	1	Food waste
	2	Trees and grass
	3	Organic mix
Paper	4	Paper boxes
	5	Paper cartons
	6	Other paper containers
	7	Cardboard
	8	Newspaper
	9	Magazines, books, white paper
	10	Other paper
Plastics	11	PE bottles
	12	PET bottles
	13	Other bottles
	14	Super bags
	15	White foam
	16	Other colour foam
	17	Tray and cups
	18	Film containers
	19	Other plastic
	20	Goods packages
Glass bottle	21	Transparent bottles
	22	Brown bottles
	23	Green bottles
	24	Other colour bottles
	25	Other glass
Metals	26	Steel cans
	27	Aluminium can
	28	Steel
	29	Aluminium
	30	Stainless steel
	31	Other metals
Others	32	Fiber and clothes
	33	Paper diapers
	34	Rubber and leather
	35	Pottery
	36	Compound goods
	37	Other
Hazardous	38	Bulbs/fluorescent lights
	39	Batteries
	40	Spray can

2.5 Landfill

The municipal solid waste landfilling represents the cheapest option in many countries. Landfills are commonly in western Europe, North America and Asia. Second most often used way of getting rid of waste is incineration, either with or without energy recovery. Third one is recycling and composting. The OECD reported that in 2004 on average of the OECD countries comprised 58% landfilling, 20% incineration, of which 11% also included incineration with energy recovery, 16% recycling and 6% composting [Williams, 2005]. Between 1990 and 2000, the number of landfills for municipal solid waste in Germany is reduced from 8,273 to 333. [UBA, 2006]. There are only 2 landfills in Luxembourg. In South and Southeast Asian countries indicate the open dumping to be 90% in India, 85% in Sri Lanka, 65% in Thailand and 50% in China [Visvanathan et al., 2005]. [Chiemchaisri et al., 2008] gives even 78% for open dumping in Thailand in 2008. The other methods are composting and incineration. One of the methods applied is the vermi-composting using tiger worms to reduce the biodegradable in Barommatrilokanat 21 community in Phitsanulok province, Thailand.

Landfill concept

A landfill is any form of waste land, ranging from an uncontrolled rubbish dump to a full containment site engineered with high standards to protect environment. The concept is dumping waste into a landfill site, waste is spread in a layer and then compacted with a compressor. It is the most economical form of municipal solid waste disposal as adversed environmental effects and other risks and inconveniences are minimized, thereby allowing waste to decompose under controlled conditions until it eventually transform into relatively inert, stabilized material [Wichitsathian, 2004].

Landfills worldwide can be classified into 3 types according to [Ashford and Chomsurin, 2000] as follows:

1. The open dump is an open place for dumping waste without environmental problems concerns.
2. The non-engineered landfill is operated with daily cover on disposed waste in order to prevent unpleasure smells and vermins.
3. The engineered landfill is the type of landfill which consists of cell construction, suitable geological and technical barriers such as geomembrane, a compacted clay line, leachate and biogas controlling systems.

2.5.1 Classical landfill

Old waste dumps are places which were constructed lacking of geological and technical barrier. Until 1970's, all unsorted waste was disposed in this kind of landfills. From 1972, Germany had the "Geordnete Deponie", the operational procedure is simply dumping waste in landfill body and given a compaction in order to reduce the volume of waste. The incoming waste is generally spread in layers. Waste is sometime heaped with a height of between 3 – 4 meters depending on the site of the disposal areas. The waste body is extremely unstable. The waste contained large particle size of waste. The untreated waste in such a classical landfill contained high harmful substances. The waste itself produces such a high amount of leachate. Waste which is more deeply embedded in landfill is subject to anaerobic conditions. The aerobic degradation process is very low and caused high methane production. Classical landfill is a major source of methane gas. There is very long period of time to convert waste into mineral, stabilized materials, at least more than 20 years. An open classical landfill with waste without pretreatment looks unsatisfactory with unpleasure smells of methane production, dust and windblown paper and plastics. After the classical landfill had been closed, extensive post-closure, monitoring and remedial work over many decades in order to ensure that leachate and methane gas remain contained are required.

From 1980's, classical landfills were constructed with a liner system. Characteristics of classical landfill with liner consist of the following system parts, starting from the bottom of landfill as follows.

1. Liner / base sealing system: the function of this liner is to limit downward water movement in order to protect the groundwater and areas surrounding the landfill. It consists of a low hydraulic conductivity geomembrane or clay layer. A clayey liner has a thickness of at least 60 cm or a mixed compacted clay and geosynthetic material must having a minimum saturated hydraulic conductivity of 10^{-9} m/s as standard [Tossiri, 2001].
2. Leachate collection system: the function is to collect and drain the leachate out of landfill. PVC or HDPE pipe with a diameter not less than 4 cm is placed in soil layer which has a minimum hydraulic conductivity of 10^{-5} m/s and thickness of a minimum 30 cm [Tossiri, 2001] and [Dwyer, 2003].
3. Waste: this part contains different types of disposed municipal waste (organic and inorganic waste), the physical, chemical and micro – biological processes take place largely.
4. Final cover: a top layer with vegetation or an armored top surface. This layer should be capable of sustain non – woody plants, have an adequate water holding capacity and be sufficiently deep to allow for expected, a long – term erosion losses

as well as protect the underlying soil layer from damage due to freeze/thaw circles [Dwyer, 2003].

Engineered or Sanitary landfill system can be further divided into 4 different levels [Körner et al., 2006]. Table 2.11 presents technical elements of each engineered landfill levels. Figure 2.8 presents a schematic diagram of a composition of typical engineered landfill.

Table 2.11: Level of engineered landfill system [Körner et al., 2006]

Item	Level 1	Level 2	Level 3	Level 4
Soil cover	+	++	++	++
Embankment		++	++	++
Drainage facility		++	++	++
Gas venting		++	++	++
Leachate collection			++	++
Leachate recirculation			++	++
Leachate treatment				++
Liner				++

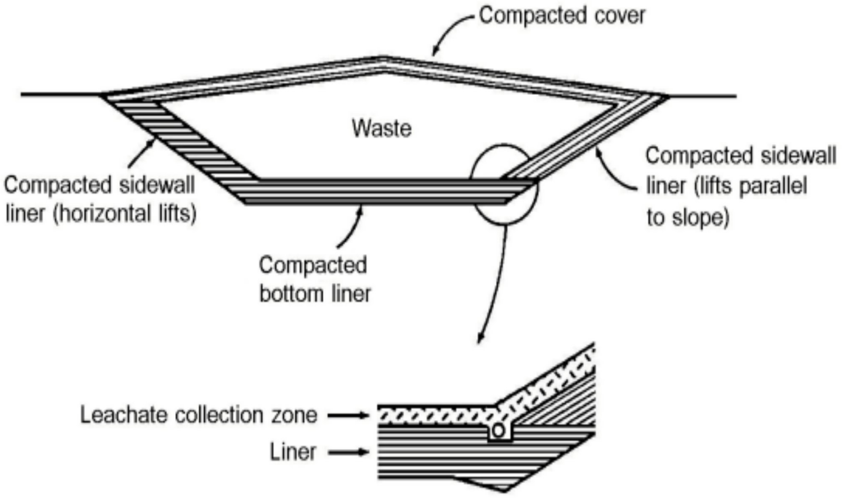

Figure 2.8: Schematic diagram of an engineered landfill [Tossiri, 2001]

2.5.2 Modern landfill according to TASi 1993

According to TASi 1993 a modern landfill must include methods to contain leachate such as a clay or plastic lining material. Deposited waste is normally compacted to increase its density and stability. Many landfills also have landfill gas extraction systems installed to extract the landfill gas. Gas is pumped out of the landfill using perforated pipes and flared off or burnt in a gas engine to generate electricity. MBT landfill is a kind of modern landfill which receives only pre-treated municipal solid waste. According to German waste management ordinances require location, design and operation of landfills and the composition of waste accepted for landfilling (landfill classification criteria). The technical instruction takes a multi – barrier approach, combining four barrier components starting from bottom to top:

1. Geology
2. Liner
3. Waste
4. Final covering system

The final covering system is importance for long term performance of landfills for lasting containment and attaching the greatest importance to the composition of waste. The composition requirements, organic constitutions must be largely mineralized and soluble harmful substances converted into stable insoluble materials [UBA, 2006].

The German Waste Disposal regulation classifies the landfills according to the type of waste, they are as listed below [Körner et al., 2006].

1. Class 0 : Inert waste
2. Class I : Quite inert municipal solid waste
3. Class II : Municipal solid waste
4. Class III : Hazardous waste
5. Class IV : Underground disposal site

Final covering system

Figure 2.9 presents a standard final covering system for MBT landfill. Three criteria for barrier are low hydraulic conductivity, sufficient strength for stability during construction and operation and resistance to excessive dessiccation cracking during the lifetime of the landfill. Generally, it is complex and expensive. The geological barriers consist of layers as followings:

- Equalizing layer has a thickness more than 0.5 m.
- Mineral sealing layer is normally a compacted clay and it has a thickness more than 0.5 m and a minimum hydraulic conductivity of 10^{-9} – 10^{-10} m/s.
- Fiber layer is normally a plastic geomembrane has a thickness at least 2.5 cm.
- Drainage layer has a thickness at least 30 cm.
- Land restoration has thickness at least 100 cm.

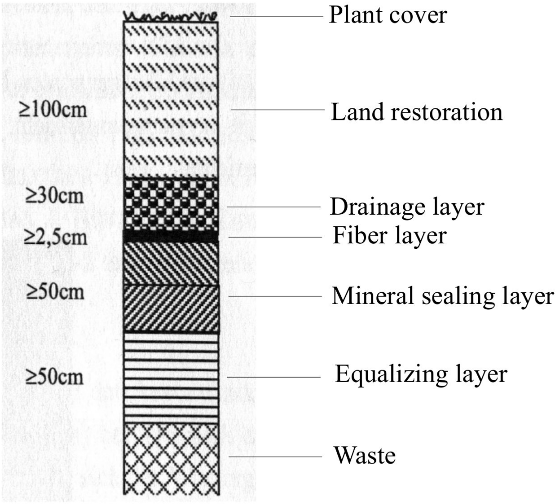

Figure 2.9: Schematic diagram of final covering system for landfill [Xie, 2003]

Base sealing system

Figure 2.10 presents a standard base sealing system which is found in German landfills. The multi – barrier of layers consist of geological and liner materials from bottom to top as follows:

- Mineral sealing layers: montmorillonite layer of ca. 1 m and Kaolinite layer of ca. 75 cm.
- HDPE layer ca. 2.5 mm and geomembrane
- Sand layer has a thickness ca. 15 cm.
- Geotextile layer
- Filter layer has a thickness ca. 50 cm.
- Fine particle of waste has a thickness ca. 2 m.

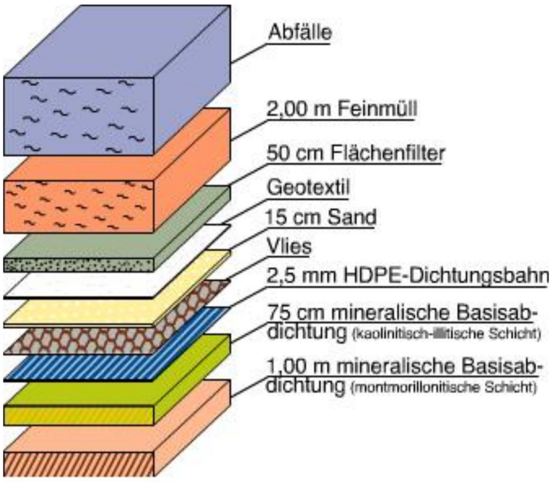

Figure 2.10: Schematic diagram of base sealing system for landfill [Eiterköpfe, 2009]

2.5.3 Effects of MBT material on landfill sites

In comparison to the conventional form of disposal, mechanical and biological treatment is considered to have advantages. MBT material is more dense than the untreated waste which is build in landfill site. MBT material allows hardly any percolation of rainwater, especially if the material shows sufficient compaction in the landfill. Production of methane hardly occurs. This is because of the easily degradable organic components have been transformed to inert material. There is no bad smell emissions from the landfill site. The waste body reaches a very high stability. Waste reduction is double of the height in landfill. The lifetime of landfill site is surely longer than the conventional landfill. MBT material is able to be completely stabilized in landfill sites in a shorter time period of about 4 – 5 years after the final closure stage while at least 20 – 30 years for conventional landfills.

2.5.4 Utilization of MBT materials

MBT waste in its total is delivered to the landfill site. This material is transformed of the organic waste to an inert content at a low level.

Trend of utilization for MBT material is increasing for example in Thailand. Since the material has a suitable properties to be reuse. Another reason is for extending life time of the landfill site. The material is subjected for an extended period of time about 9 months to an aerobic decomposition. Material is all transformed to an inert material. Coarse part of material is good use of the material for a refuse – derived fuel (RDF) or the material is sieved and the compost part is utilized as a low grade compost. This part of material has suitable properties for use as biofilter layer in the final cover of the landfill or even as temporary cover during the MBT process. This utilization should be restricted to landfill sites since the material may be polluted from parts of the waste (e.g. heavy metals from toxic / hazardous waste components) [Schoell, 2006]. However, there are two different opinions of the utilization for MBT material in the European countries. One goes for build in the material at a landfill site is already the suitable way because there are uncertainties about availability of markets for RDF for energy recovery and either producing a low grade compost. Another supporting idea is the gate fees and landfill tax would still be required for any final MBT material being sent to landfill. As well as, the Department of Food, Environment and Rural Affairs has said that the current standard of MBT technology is very unlikely to produce an output to correspond with what it defines as a compost. However, some have another preferable option that spending more time on the preparation of the MBT material could mean a local authority could make good use of the material for composting [Eminton, 2005].

Chapter 3

Methodology

3.1 Framework

The achievement in solid waste reduction needs to be realized by an appropriate treatment. Suitable performance of technology depends on different factors in national/local legislation, understanding of importance, funds, knowledge, experience and etc. This comparison of the three different countries for MBT material in Europe and Southeast Asia is a type of systems knowledge in order to develop and encourage capacity in solid waste management for landfill operators.

The framework of this thesis is based on answering research questions from a comparative study:

- Can the MBT technology be approved as a suitable solid waste technology and management based on the example of Germany, and trends in Luxembourg and Thailand?
- How are differentiations in the MBT operations as well as characteristics of final MBT materials relevant to lifestyles and types of waste in different target areas?
- What is an appropriate treatment to optimize a sustainable landfill technology for solid waste disposal and to strengthen regional collaboration between European and Asian with respect to environmental issues?

3.2 Process of research

Sampling collection

The obtained samples from each country were collected by drilling and digging from composting heaps and windrows after pre-treatment process with the help of people at landfills. The amount and age of depositions were dependent upon the permission and the possibility of each study area. The waste sample was randomly selected according to composite sampling standard method at each landfill. The size of sample to be characterised was reduced to manageable sizes before characterisation was carried out. The size reduction was achieved by the quartering[1] method.

Description of samples

Different samples had been taken from the Muertendall and the Fridhaff landfills in Luxembourg. The Eiterköpfe, the Linkenbach and the Singhofen landfills in Germany. The Phitsanulok landfill in Thailand. The rotting period of each samples is shown in Table 3.1.

Table 3.1: The details of waste samples from the study areas

Country	Place	Sample	Rotting period	Date of sampling
Luxembourg	Muertendall	sample 1 (redeposited)	> 20 years	June 2008
		sample 2	6 – 10 years	June 2008
		sample 3	1 – 2 years	June 2008
Luxembourg	Fridhaff	sample 1	6 weeks	August 2008
Germany	Eiterköpfe	sample 1	20 weeks	August 2008
		sample 2	40 weeks	August 2008
Germany	Linkenbach	sample 1	25 weeks	August 2008
		sample 2	35 weeks	August 2008
Germany	Singhofen	sample 1	15 weeks	September 2008
Thailand	Phitsanulok	sample 1	48 weeks	October 2008

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[1] Quartering is a method to reduce the amount of sample; the gross sample is mixed and piled in a conical heap. The cone is flattened to approximately one quarter of its original height. The flattened heap is divided into four equal portions. Two opposite quarters are rejected and the remaining pair is mixed together. The above procedure is then repeated until the required sample quantity is obtained.

Experimental study

The samples were first analyzed for size fraction on the day of collection into the three following groups by the sieving method (dry sieve):

1. small size with a diameter of < 10 mm
2. medium size with a diameter of 10 – 40 mm
3. large size with a diameter of > 40 mm

A small portion of each group was sampled immediately for water content analysis. The rest of samples were stored at the cold, dark room prior to other physical and chemical analysis.

The works were divided into three parts:

- Physical and chemical analysis for the separated three groups.
- Particle size distribution and geotechnical tests for the small size with a dimeter of < 10 mm.
- Determination for the leaching potential from their extracted eluate.

Figure 3.1 shows parameters used to determine the MBT material characteristics. The microbial characteristic of the MBT material is not determined for this study.

The total numbers of experiments for physical and chemical characteristics can be seen in Table 3.2, Table 3.3 and Table 3.4.

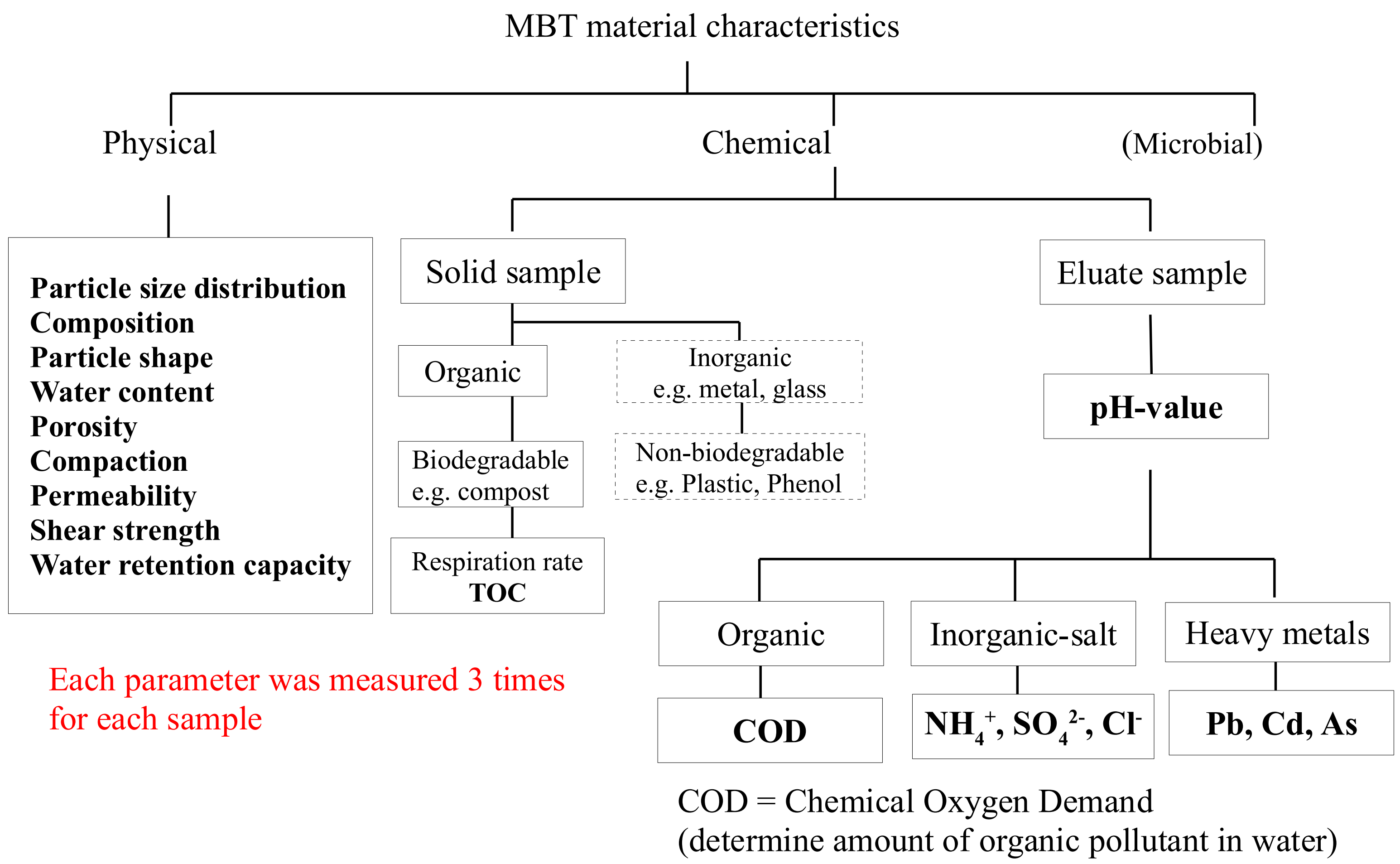

Figure 3.1: Flowchart of experimental study to determine MBT material characteristics

Table 3.2: Amount of experiments for material characterization

Parameters	**Luxembourg**				**Germany**					**Thailand**
	MD			**FH**	**EK**		**LB**		**SH**	**PL**
	I	II	III	I	I	II	I	II	I	I
Disposed duration	>20 yrs[a]	6-10 yrs[b]	1-2 yrs[c]	6 wks	20 wks	40 wks	25 wks	35 wks	15 wks	1 yr
1. Water content										
a. < 10 mm	3	3	3	3	3	3	3	3	3	3
b. 10-40 mm	3	3	3	3	3	3	3	3	3	3
c. > 40 mm	3	3	3	3	3	-	3	3	3	3
2. pH										
a. < 10 mm	3	3	3	3	3	3	3	3	3	3
b. 10-40 mm	3	3	3	3	3	3	3	3	3	3
c. > 40 mm	3	3	3	3	3	-	3	3	3	3
3. TOC solid										
a. < 10 mm	NA	NA	NA	3	3	3	3	3	3	3
b. 10-40 mm	NA	NA	NA	3	3	3	3	3	3	3
c. > 40 mm	NA[d]	NA	NA	3	3	-	3	3	3	3
Total	18	18	18	27	27	18	27	27	27	27

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[a] redeposited waste

[b] not standard pretreated waste

[c] not standard pretreated waste

[d] not analyzed

The total number of experiments for physical characteristics is shown in Table 3.3.

Table 3.3: Amount of experiments for physical characteristics

Parameters	Luxembourg < 10 mm	Germany < 10 mm	Thailand < 10 mm	Total
Particle size distribution	3	3	3	9
Particle shape	3	3	3	9
Porosity	9	9	9	27
Compaction	3	3	3	9
Permeability	3	3	3	9
Shear strength	2	2	2	6
Water retention capacity	3	3	3	9
Mineralogy	3	3	3	9
Total	29	29	29	87

The total number of experiments for extracted eluate quality is shown in Table 3.4.

Table 3.4: Amount of experiments for extracted eluate quality

Parameters	Luxembourg < 10 mm	Germany < 10 mm	Thailand < 10 mm	Total
pH value	3	3	3	9
Chemical oxygen demand (COD)	3	3	3	9
Ammonium (NH_4^+)	3	3	3	9
Sulfate (SO_4^{2-})	3	3	3	9
Chloride (Cl^-)	3	3	3	9
Lead (Pb)	3	3	3	9
Cadmium (Cd)	3	3	3	9
Arsenic (As)	3	3	3	9
Total	24	24	24	72

3.3 Parameters and analytical methods

All parameters have been determined by the analytical methods and regulations listed in Table 3.5.

Table 3.5: Parameters and their analytical methods

Parameter	Method of Analysis	Equipment Used
Solid sample		
Particle size	DIN 18 123	Standard sieve equipment
Composition	% mass weight	Weights
Particle shape/mineralogy	SEM method	Scanning Electron Microscope
Water content	DIN 18 121-1	Oven 105 °C
Porosity	DIN EN 12901	Weights, Beaker
Compaction	DIN 18127	Compaction molds
Permeability	DIN 18 130	PVC tube
Shear strength	DIN 18137-1	Direct shear apparatus
Water retention capacity	DIN 18 132	Enslin and Neff device
Total Organic Carbon	Combustion	Combustor
Eluate sample		
pH-value	DIN 38 404 - C5	pH meter
Chemical Oxygen Demand	Open Reflux method	Refluxing flasks
Ammonium (NH_4^+)	Photometric method	Spectrophotometer
Sulfate (SO_4^{2-})	Photometric method	Spectrophotometer
Chloride (Cl^-)	Titration method	Flasks
Pb, Cd, As	Emission spectroscopy	ICP-OES analyzer

3.3.1 Particle size analysis

Sieving method is commonly used in the basic physical test of coarse fraction of soil with various sieve diameter equipments. Sieving can be done either dry or wet. The method is simple shaking of the sample in sieves until the amount retained becomes more or less constant. At the end of the test, the fractions retained on each sieve are weighted. Screening characteristic of pre-treated waste was done by the method of sieving (dry sieve). After mixing and homogenizing of the waste sample. It was put through a sieve diameter of 10 and 40 mm. The percent retained is represented by weight retained on a sieve W_r divided by total weight of sample W_t, each separated group is calculated in percentage as the following equation.

$$Percent(\%) = 100\left(\frac{W_r}{W_t}\right) \tag{3.1}$$

Measure of gradation

Gradation is a descriptive term that refers to distribution and size of fine grains in a soil. It is determined by the gradation analysis of soils and is presented in the form of a cumulative, grain-size curve in which particle sizes are plotted logarithmically with respect to percentage (by dry mass) of the total specimen plotted to a linear scale. A soil is said to be poorly sorted when a good representation of all particle sizes exists from the largest to the smallest. A soil is considered to be well sorted if an excess or a deficiency of certain particle sizes occurs within the limits of the minimum and maximum sizes or if the range of predominant sizes falls within three or less consecutive sieve-size intervals on the gradation curve. A well sorted soil is call uniform if all the particles are about the same size. When there is an absence of one or more intermediate sizes, the material is said to have a gap or skip gradation. To determine whether a material is poorly sorted or well sorted, Coefficient of uniformity (C_u) and Coefficient of curvature (C_c) describing the extent and shape of the gradation curve have been defined as follows.

- The uniformity coefficient

$$C_u = \frac{D_{60}}{D_{10}} \tag{3.2}$$

where:

(C_u) = coefficient of uniformity
D_{10} = the size of sieve at 10 percent passing
D_{60} = the size of sieve at 60 percent passing

- Coefficient of gradation or curvature

$$C_c = \frac{(D_{30})^2}{D_{10} * D_{60}} \tag{3.3}$$

where:

(C_c) = coefficient of curvature
D_{10} = the size of sieve at 10 percent passing
D_{30} = the size of sieve at 30 percent passing
D_{60} = the size of sieve at 60 percent passing

D_{60} is diameter of soil particles for which 60% of the particles are finer (for example 60% of the particles are finer and 40% coarser than D_{60}).

D_{50} is an average particle size.

D_{10} is an effective particle size. It is 10% of particle are finer and 90% coarser than D_{10} size.

$C_u > 4 - 6$ is considered to be poorly sorted soil ($>$ 4 for gravels and $>$ 6 for sand).

C_c between $1 - 3$ is considered to be poorly sorted.

If one or both of these criteria are not satisfied, the soil is well sorted. A well sorted soil having a coefficient of uniformity (C_u) of 2.0 or less is uniform [Farrar, 2004].

Typical characteristics of grain size distribution curves are:

- Steep curve means low C_u values (well sorted, uniformly graded)
- Flat curve means high C_u values (poorly sorted)

Table 3.6 shows soil classification based on particle size (after Frederic Gladstone, 1992)

Table 3.6: Particle size classification of soil after [Frederic Gladstone, 1992]

Types of material		Size (mm)
Boulders		Over 200
Cobbles		60 – 200
	Coarse	20 – 60
Gravel	Medium	6 – 20
	Fine	2 – 6
	Coarse	0.6 – 2
Sand	Medium	0.2 – 0.6
	Fine	0.06 – 0.2
	Coarse	0.02 – 0.06
Silt	Medium	0.006 – 0.02
	Fine	0.002 – 0.006
Clay		< 0.002

3.3.2 Composition analysis

For the composition analysis, the waste is categoried in the following :

1. Organics
2. Plastics
3. Glass/ceramic
4. Paper
5. Metals
6. Others

The composition analysis for MBT waste was determined by separation of the waste into different categories. The sample has been reduced to a workable size of approximately 1 m^3, the procedure is presented as follows:

- Firstly pick out the larger primary waste fractions. Then separate the primary fractions into their respective secondary fractions where required. Depending on the objectives of the study, the fractions may have to be sorted into tertiary fractions as well. Placing each fraction in a demarcated area, container or bin liner.
- Record the weight of each fraction. Remember to weigh the containers separately as their weight has to be deducted from the various fractions. The total weight of the sample can be determined by adding the weight of all the fractions – care should therefore be taken that none of the fractions are lost, including any fines and ash.
- The total weight of the sample can be determined by adding the weight of all the fractions. The percent by weight of each composition can be represented by weight of each item W_i divided by total weight of sample W_t, as follows:

$$Percent(\%) = 100\left(\frac{W_i}{W_t}\right) \tag{3.4}$$

3.3.3 Particle shape

a) Preparing the specimen

Samples have to be dry prepared to withstand the vacuum inside the microscope. In order to view non-conductive samples such as soils, ceramics or plastics, the sample must be covered with a thin layer of a conductive material. A sputter coater coats the sample with gold atoms. The purpose is to make non-metallic samples electrically conductive. The sputter coater uses argon gas and a small electric field. The sample is placed in a small chamber which is at vacuum. Argon gas is then introduced and an electric field is used to cause an electron to be removed from the argon atoms to make the atoms ions with a positive charge. The Ar ions are then attracted to a negatively charged piece of gold foil. The Ar ions act like sand in a sandblaster, knocking gold atoms from the surface of the foil. These gold atoms now settle onto the surface of the sample, producing a gold coating [Scott, 2009].

b) Function of SEM

The scanning electron microscope (SEM) is a type of electron microscope that images the sample surface by scanning it with a high-energy beam of electrons in a raster scan pattern. The electrons interact with the atoms that make up the sample producing signals that contain information about the sample's surface topography, composition and other properties such as electrical conductivity. The types of signals produced by an SEM include secondary electrons, back scattered electrons (BSE), characteristic x-rays, light (cathodoluminescence), specimen current and transmitted electrons. These types of signal all require specialized detectors for their detection that are not usually all present on a single machine. The signals result from interactions of the electron beam with atoms at or near the surface of the sample. In the most common or standard detection mode, secondary electron imaging or SEI, the SEM can produce very high-resolution images of a sample surface, revealing details about 1 to 5 nm in size. Due to the way these images are created, SEM micrographs have a very large depth of field yielding a characteristic three-dimensional appearance useful for understanding the surface structure of a sample.

3.3.4 Water content

Water content is the quantity of water contained in waste material. The water content of the waste samples was measured by the gravimetric method, that is drying the sample at 105 °C in oven (department of Geology, University of Trier) and calculate the weight percentage with the following equation.

$$M = 100\left(\frac{W - D}{W}\right) \tag{3.5}$$

Where:

M = water content %

W = initial weight of sample (g)

D = weight of sample after drying at 105 °C (g)

3.3.5 Porosity

Porosity is a measure for the void space in a porous medium that will be occupied by fluid in the case of saturation. For the unsaturated situation, void space may be partially occupied by water as a mobile or stagnant liquid film on the surface of the pores, and partially by gas (air landfill or decomposition or soil gases). For dry condition, the void space is filled by gas. The total void space or porosity of soil can be represented by the ratio of the volume of voids V_v to the total system volume V_t.

Porosity analysis was carried out in the small size < 10 mm. The samples were screened into 3 fractions: < 10 mm, < 4 mm, and < 1 mm. Dry and loose sample of each fraction without any compaction is placed into a measuring beaker (250 mL). Gently fill the water into each beaker. Measure and record the amount of water in each beaker, subtract this amount from the starting amount to determine the total amount of water held for each size of material.

(1) To determine void ratio e (given in decimal)

$$e = \frac{V_v}{V_s} = \frac{n}{1-n} \tag{3.6}$$

(2) To determine porosity n (given in percent)

$$n = \frac{V_v}{V_t} = \frac{e}{1+e} \tag{3.7}$$

(3) To determine degree of saturation S (given in percent)

$$S = 100\left(\frac{V_w}{V_v}\right) \tag{3.8}$$

where:

V_t= total volume
V_s= volume of solid particles
V_v= total volume of voids
V_w= total volume of voids contains water

3.3.6 Compaction

Compaction test is performed to determine the relationship between the water content and the dry density of a soil for a specified compact effort, developed by R.R.Proctor in 1933. The optimum water content is the water content that results in the greatest density for a specified compact effort. Two types of compaction tests are routinely performed:

- The standard Proctor test

  The standard Proctor test is carried out using compaction molds 4 inches in diameter and has a volume of about 943 cm^3. The mold is filled with three equal layers of sample and each layer is subjected to 25 drops of the hammer (ca. 2.5 kg). Compaction test for MBT samples was done by the standard Proctor test in this study.

- Modified Proctor test

  The modified Proctor test is carried out using compaction mold 6 inches in diameter and has a volume of about 2123 cm^3. The mold is filled with five equal layers of sample and each layer is subjected to 56 drops of the hammer (ca. 5 kg).

Test procedure starts with assemble the compaction mold to the base, place some sample in the mold and compact the sample in the number of equal layers specified by the type of compaction method (the MBT samples in this study were done with the standard Proctor test). Weigh the compacted sample while it is in the mold and to the base and record the mass. Determine the wet mass of the sample by subtracting the weight of the mold and base. Then remove the sample from the mold and take water content of samples from the top and bottom of the specimen. Place the specimen in the large tray and break up the sample until it appears visually as the beginning and add more percent of water based on the original sample mass and re-mix and repeat the steps. Compute the dry density using the wet density and the water content determined as the following formula:

$$\rho_d = \left(\frac{\rho}{1+w} \right) \tag{3.9}$$

where:

ρ_d= dry density in grams per cm^3

ρ = wet density in grams per cm^3

w = water content in percent divided by 100

3.3.7 Permeability

Permeability or hydraulic conductivity is an important physical parameter of soil. This value of soil is the ability of liquid to flow through a porous medium (e.g. soil or waste). The rate of movement of the water is defined as the flow volume per unit cross sectional area of medium under the influence of a unit hydraulic gradient depends on different factors such as particle size of the material, porosity and etc. Darcy's law is valid for water flows through soils, which are assumed laminar. Permeability test for MBT samples in this study was done by the Falling Head Test method. Two types of tests are routinely performed on porous medium in Laboratory:

(1) Constant Head test: is performed only on granular mediums as the pore openings large and hence high permeability

(2) Various Head or Falling Head test: is performed in this study covered both fine-grained mediums and coarse-grained or granular soils as the pore openings are small and low permeability

Constant Head Test procedure

1. A preparation of the specimen was done following the standard Proctor test with the compaction mold (metal cylinder). The mold is filled with three equal layers of waste samples. Each layer is given 25 drops of the manual rammer (2.5 kg). Then it was wrapped around with a latex sheet. The top and end of the specimen were covered with porous stone plates. Then placing it into the cell of permeability test which had a pipe connection to allow water hose to be attached.

2. The system was set. The water ran into the top of the specimen. The flow of air pressure into the system was allowed through a pipe connection on top of the tank. Excess water flowing through the specimen ran out the outlet pipe into a collection beaker. The mass of excess water was measured and permeability was calculated using following equation (Darcy's law).

$$k = \left(\frac{Q}{t}\right)\left(\frac{L}{h_w A}\right) \tag{3.10}$$

Where:

Q = flow rate (cm^3/sec)

t = time (sec)

h_w = saturated pressure (bar)

L = length of specimen (cm)

A = cross area (cm^2)

k = coefficient hydraulic conductivity (m/sec)

Falling Head Test procedure

1. A preparation of the specimen was done following the standard Proctor test with the compaction mold (metal cylinder). The mold is filled with three equal layers of waste samples. Each layer is given 25 drops of the manual rammer (2.5 kg). The compacted sample was placed into a PVC cylinder having a height of 30 cm and diameter equal to 10 cm. The specimen was fully saturated into the water.

2. Water was gently filled into the test cylinder on top of the specimen. When the top of the test cylinder was completely full and the system was well set, the time of measuring started. The saturated hydraulic conductivity value was calculated using following equation.

$$k = \left(\frac{aL}{At}\right) ln\left(\frac{h_1}{h_3}\right) \tag{3.11}$$

Where:

a = area of falling head tube (cm^2)

h_1 = initial drop height (cm)

h_3 = final drop height (cm)

t = time (sec)

L = length of specimen (cm)

A = area of specimen (cm^2)

k = coefficient hydraulic conductivity (m/sec)

3.3.8 Shear strength

Shear strength is a common engineering property to define the stability characteristics of material. Soil has little strength compared to other material used for building a structure. Moreover, compared to maximum soil strength, large variation can exist in strength, both from soil to soil and within a given soil type, depending on how it was deposited. Shear strength of a soil consists of two parts: (1) one part dependent on the stress acting normal to the shear plane, (2) the other part is independent of that stress. The parts are called internal friction and cohesion, respectively [Farrar, 2004].

The direct shear strength test was carried out in the shear box apparatus with the MBT particle size < 10 mm under undrained condition according to DIN 18 137 (see photo of shear equipment in appendix A). The samples were nearly not compacted. They were put to fit into a cylindrical ring with a volume of 140 cm^3. Then it was placed in a circular in plan of the direct shear apparatus. Initial height of specimen was 2 cm. Rate of shear was 0.1 mm/min. Shear load is applied to the lower half of the box, the upper half being restrained by a proving ring or load cell which is used to record the shear load. Four samples were tested with increasing normal forces (20, 40, 80, 100 kN/m^2) for making a graph of shear strength's value. Both values of cohesion (c) and angle of internal friction (φ) are major results of a direct shear test. These parameters are used to evaluate a material's shear strength. The factor relating normal component of stress to shear strength was designated by tan ϕ and the unit of cohesion by c. The shear strength s, may then be expressed as:

$$s = c + (\phi)tan(\sigma) \tag{3.12}$$

where:

s = shear strength

c = unit of cohesion

ϕ = normal stress on the sliding surface

σ = angle of internal friction

Experimental methods to determine shear strength:

1. Direct shear test
2. Triaxial shear test

3.3.9 Water retention capacity

The water retention capacity indicates the nature of the material in holding water. Water is held in the soil because of the attraction between soil solids and water. This force can be measured by water tension. The experiment was performed using the Enslin device according to DIN 18132. The apparatus is filled with water up to the filter platen and a small amount of the oven-dried sample is placed on the platen. The very fine fraction of sample with diameter less than 0.4 mm is taken of 1 g. At suitable time intervals, the amount of absorbed water is measured on the graduated capillary. The water retention capacity test is terminated when the sample is completely soaked in two successive time intervals. With a duration > 1 hour, V_w is the volume of water uptake of the sample and V_k is the volume of water evaporated which is taken in calculating equation with $\varrho = 1$ g/cm^3 and $m_d = 1$ g. The water retention capability is ratio of the final mass of absorbed water to the dry mass of the specimen.

The water retention capacity is a ratio of the final mass of absorbed water to the dry mass of the specimen. Volumetric water content at the recorded water retention capacity (1 g/cm^3 = density of water at 20°C) was calculated in percent by weight. The powder samples of MBT material were screened into 3 fractions: < 0.25 mm, 0.25 – 0.315 mm, and 0.315 – 0.4 mm.

$$m_w = \left(\frac{V_w}{V_k}\right) \tag{3.13}$$

$$W = \left(\frac{m_w}{m_d}\right) \tag{3.14}$$

where:

V_w = volume of water uptake of the sample

V_k = volume of water evaporated

m_w = final mass of absorbed water

m_d = 1 g.

W = water retention capacity

3.3.10 Total Organic Carbon

Total organic carbon is the amount of carbon bound in an organic compound. A typical analysis for TOC measures both the total carbon present as well as the inorganic carbon (IC). Subtracting the inorganic carbon from the total carbon yields TOC. Another common variant of TOC analysis involves removing the IC portion first and then measuring the leftover carbon. This method involves purging an acidified sample with carbon-free air or nitrogen prior to measurement, and so is more accurately called non-purgeable organic carbon (NPOC).

The TOC of the MBT waste samples was analyzed according to the method of the combustion (burning solid sample at 600 °C) at the Central Analytical Center, Faculty of Natural Resources, Prince of Songkla University in Thailand.

TOC solid

1. Calculate % Moisture in sample

$$M(1) = 100\left(\frac{W_2 - (W_3 - W_1)}{W_2}\right) \tag{3.15}$$

   Where:
   $M(1)$ = moisture content %
   W_1 = weight of crucible after drying at 105 °C for 1 hour (g)
   W_2 = weight of sample (g)
   W_3 = weight of sample and crucible after drying at 105 °C for 5 hour

2. Calculate % Ash in sample

$$M(2) = 100\left(\frac{W_2 - (W_3 - W_1)}{W_2}\right) \tag{3.16}$$

   Where:
   $M(2)$ = moisture content %
   W_1 = weight of crucible after drying at 600 °C for 1 hour (g)
   W_2 = weight of sample (g)
   W_3 = weight of sample and crucible after drying at 600 °C for 5 hour

3. Calculation % Organic Carbon

$$Organic - Carbon(\%) = (100 - M(1) - M(2))(58) \tag{3.17}$$

3.3.11 pH-value

pH is a measurement of the acidity or basicity of a solution. It is an important chemical parameter for environmental studies and many other applications. Determination of pH-value in waste is to evaluate the stabilization condition of waste which can be related to the degradation process. A measurement is commonly done by pH meter which can measure also the temperature of solution as well. The pH was measured by mixing 50% (by wet weight) waste sample and distilled water into a 1 L glass beaker. When the solution is well mixed and reached equilibrium at 25 °C, the pH probe was placed into the beaker and the reading was obtained. Pure water is said to be neutral. The pH for pure water at 25 °C (77 °F) is close to 7.0. Solutions with a pH less than 7 are said to be acidic and solutions with a pH greater than 7 are said to be basic or alkaline. The pH-value was analyzed by the pH meter at the temperature of 25 °C for the extracted eluate of waste samples (the three groups of the sieved particle size) see Table 5.8 at the department of Geology, University of Trier.

The following tests were done by using the extracted eluates of the MBT material from each country to determine the amount of potential pollutants and leaching capacity of the MBT material in its early stage (prior to sending them to landfills). The sample was filled with water in the ration of standard procedure 1:10 solid/liquid ration and 24 hours shaking. The analysis was done at the Central Equipment Division, Faculty of Science, Prince of Songkla University, Songkhla province, Thailand.

3.3.12 Determination of Chemical Oxygen Demand

The open reflux method is suitable for a wide range of wastes where a large sample size is preferred. A sample is refluxed in strongly acid solution with a known excess of potassium dichromate. After digestion, the remaining unreduced $K_2Cr_2O_7$ is titrated with ferrous ammonium sulfate to determine the amount of $K_2Cr_2O_7$ consumed and the oxidizable matter is calculated in terms of oxygen equivalent.

Test procedure:

Reagents:

1 g. of $HgSO_4$, $K_2Cr_2O_7$ solution, sulfuric acid reagent

- Add 10 mL sample into refluxing flask. Add 1 g $HgSO_4$, several glass beads, and very slowly add 5.0 mL sulfuric acid reagent, with mixing to dissolve $HgSO_4$. Cool while mixing to avoid possible loss of volatile materials. Add 25 mL 0.04167M $K_2Cr_2O_7$ solution and mix.

- Connect the refluxing flasks with Reflux apparatus, consisting of 500 or 250 mL erlenmeyer flasks. Attach flask to condenser and turn on cooling water. Add remaining sulfuric acid reagent (15 mL) through open end of condenser. Continue swirling and mixing while adding sulfuric acid reagent. Cover open end of condenser with a small beaker to prevent foreign material from entering refluxing mixture and reflux for 2 h.

- Cool and wash down condenser with distilled water. Disconnect reflux condenser and dilute mixture to about twice its volume with distilled water. Cool to room temperature and titrate excess $K_2Cr_2O_7$ with Standard ferrous ammonium sulfate (FAS), using 0.10 to 0.15 mL (2 to 3 drops) ferroin indicator. Although the quantity of ferroin indicator is not critical, use the same volume for all titrations. Take as the end point of the titration the first sharp color change from blue-green to reddish brown that persists for 1 min or longer. Duplicate determinations should agree within 5% of their average.

- Determination of standard solution: Evaluate the technique and quality of reagents by conducting the test on a standard potassium hydrogen phthalate solution.

Calculation:

$$COD = \left(\frac{A - B}{S}\right)(N)(8000) \tag{3.18}$$

where:

COD = Chemical Oxygen Demand in mgO_2/L

A = Standard ferrous ammonium sulfate (FAS) (mL) used for blank

B = Standard ferrous ammonium sulfate (FAS) (mL) used for sample

S = sample (mL).

N = molarity of FAS, and

8000 = milliequivalent weight of oxygen X 1000 mL/L.

3.3.13 Determination of Nitrogen content

Nitrogen is one of five major elements found in organic materials. Method is called Kjeldahl and consists of three steps.

Test procedure:

1. Digestion

   Weighing out approximately 1 g of sample and placing into a digestion flask with 12 – 15 mL of concentrated sulfuric acid. Adding 7 g of K_2SO_4 and a copper. Bringing the digestion flask to a rolling boil (370 – 400 °C). Heating the mixture until fumes can be seen and continuing heating for about 60 – 90 mins. Cooling the flask and adding 250 mL water.

2. Distillation

   Adding $NaOH$ and distilling the ammonia by converting it to a volatile gas and then trapping the distilled vapors in a special trapping solution of 15 mL HCl. Removing the trapping flask and rinsing the condenser with water.

3. Titration

   Adding an indicator dye to the acid/ammonia trapping solution. Putting a standard solution $NaOH$ into the buret and slowly adding small amounts of $NaOH$ solution to the acid solution with the dye. The endpoint is indicated by the dye turns to orange. Record volume of the $NaOH$.

Calculation:

$$\%N = \left(\frac{(A-B)(N)(14)(100)}{C}\right) \tag{3.19}$$

where:

N = molarity of standard Sulfuric acid solution

A = Volume of standard Sulfuric acid solution used for sample titration (cm^3)

B = Volume of standard Sulfuric acid solution used for blank titration (cm^3)

C = Weight of sample (mg)

3.3.14 Determination of Sulfate

Sulfate in Eluate sample was measured by the method of turbidity. Glycerol in solution of HCl reacts to $BaCl_2$ and appear $BaSO_4$.

Test procedure:

Reagents:

Conditioning Reagent (Glycerol 50 mL, Ethanol 95% 100 mL, concentrated HCl 30 mL. $NaCl$ 75 g. distilled water 300 mL.), $BaCl_2$, Anhydrous Na_2SO_4 147.9 mg.

- Fill Eluate sample of 100 mL in a flask and add Conditioning Reagent of 5 mL into the flask of sample. Stir with magnetic stirrer. Then add $BaCl_2$ of approximately 0.2 – 0.3 mL (1 spoon).
- Measure the time immediately after adding $BaCl_2$ and stirring for 1 minute and measure the turbidity with Nephelometer.
- Prepare standard graph of standard Sulfate solutions for various concentrations of 500, 1000, 1500, 2000, 2500 and 3000 micro gram. Sulfate solutions of 5, 10, 15, 20 and 30 mL of each concentration are mixed with distilled water. Total volume of each flask is 100 mL and analyze them for turbidity and plot for a graph.

Calculation:

$$SO_4 = \left(\frac{S}{W}\right) \tag{3.20}$$

where:

SO_4 = Sulfate in mg/L

S = Sulfate (μg)

W = sample (mL)

3.3.15 Determination of Chloride

Chloride is found in natural water resources such as ocean, lake or river. Chloride combines with other elements such as Na, Ca and Mg. Combination of Chloride and those elements are in compounds of $NaCl$, $CaCl_2$ and $MgCl_2$.

Test procedure:

Reagents: silver nitrate ($AgNO_3$) 4.792 g. and potassium chromate (K_2CrO) 5 g.

- Fill 50 – 100 mL sample in 250 mL erlenmeyer flasks.
- Add solution of 1 mL K_2CrO.
- Titrate with $AgNO_3$ until the brown-red suspended solid of Ag_2CrO_4 appear in sample
- Record used volume of $AgNO_3$ of the titration.
- Preparation for Blank sample

Calculation:

$$Cl = \left(\frac{A - B}{S}\right)(1000) \tag{3.21}$$

where:

Cl = Chloride in mg/L

$A = AgNO_3$ (mL)

B = blank

S = sample (mL)

3.3.16 Analysis of Lead, Cadmium and Arsenic

A heavy metal is a member of an ill-defined subset of elements that exhibit metallic properties which would mainly include the transition metals, some metalloids, lanthanides, and actinides. Some of them are dangerous to health or to the environment (e.g. Hg, Cd, As, Pb, Cr), some may cause corrosion (e.g. Zn, Pb), some are harmful in other ways (e.g. Arsenic may pollute catalysts). Within European community the 13 elements of highest concern are As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mn, Ni, Pb, Sn and Tl, the emissions of which are regulated in waste incinerators. Waste derived fuels are especially prone to contain heavy metals so they should be a central concern in a consideration of their use.

Heavy metals (Pb, Cd, As) were measured in the extracted eluate of waste sample. The heavy metals in eluate were analyzed using an analyzer Inductively Coupled Plasma-Optical Emission Spectrophotometer (ICP-OES).

Chapter 4

Sites characteristics

Three countries were chosen for this comparative study due to their unique way of MBT implementation. According to the Table 3.1 different samples from the following MBT plants and landfills had been taken for a comparison of sample characteristics.

- Luxembourg:
  Fridhaff in Diekirch/Erpeldange, Muertendall[1] in Flaxweiler

  Locations of Fridhaff MBT plant and Muertendall landfill are shown in Figure 4.1.
- Germany:
  Linkenbach in Neuwied, Singhofen in Rhein-Lahn, Eiterköpfe in Koblenz districts

  Locations of Linkenbach MBT plant, Singhofen MBT plant and Eiterköpfe landfill are shown in Figure 4.2.
- Thailand:
  Phitsanulok in Phitsanulok province

  Locations of Phitsanulok landfill is shown in Figure 4.3.

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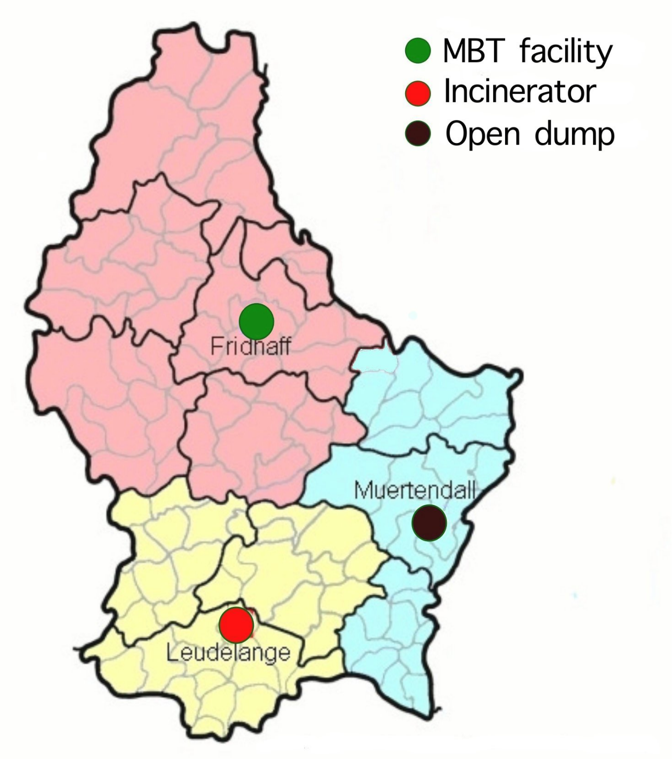
[1] at the first project meetings, the landfill responsibilities informed that their landfill is equipped with low technique of MBT implementation, the scientific analysis showed that it is not standard pretreated waste

According to data of the Ministry of Environment Luxembourg [Luxembourg, 2008]. At present, Luxembourg has only one high tech MBT facility which is located in Fridhaff, the north-east of Luxembourg. Fridhaff MBT plant is organized by SIDEC. The MBT plant treats the municipal solid waste of the northern part of Luxembourg. The responsible areas of SIDEC is presented with pink color on the map. The MSW from eastern part of Luxembourg is dumped in the Muertendall landfill which is organized by SIGRE. The responsible area of SIGRE is presented with blue color on the map.

Luxembourg has only one incinerator which is located in Leudelange, the southern part of Luxembourg. The incinerator is organized by SIDOR. The responsible areas of SIDOR is presented with yellow color on the map.

Samples from Luxembourg had been taken at Fridhaff MBT plant and Muertendall landfill. The MBT sample from Fridhaff MBT plant was only used to compare with Germany and Thailand, due to the scientific analysis showing that the characteristic of samples from Muertendall were not standard MBT material. Locations of them are shown in Figure 4.1.



Source: Ministry of Environment Luxembourg

Figure 4.1: Locations of Fridhaff MBT plant and Muertendall landfill in Luxembourg

According to reported data of the Federal Environment Agency (UBA) Germany, 2006, 66 MBT facilities and 73 waste incineration plants are available in Germany. Samples from Germany had been taken at the Linkenbach MBT plant, Singhofen MBT plant and Eiterköpfe MBT landfill which are located in the Rheinland-Pfalz region, western Germany. Locations of them are shown in Figure 4.2.

The reason for taking samples from the three locations in Germany is that the dumped waste from the Eiterköpfe landfill, is the treated MBT materials from Linkenbach and Singhofen MBT plants. To find out the relationship between fresh MBT and dumped MBT materials and to compare waste characteristics of both materials, different samples of the three locations had been studied. According to size fraction analysis in Figure 5.1, the results of size fraction of samples from the three locations are quite similar. Therefore only the MBT sample from Singhofen MBT plant was used to study and to compare with the other MBT samples from Luxembourg and Thailand. The results of MBT samples analysis of the Linkenbach and Eiterköpfe are not used for discussion in this comparison.

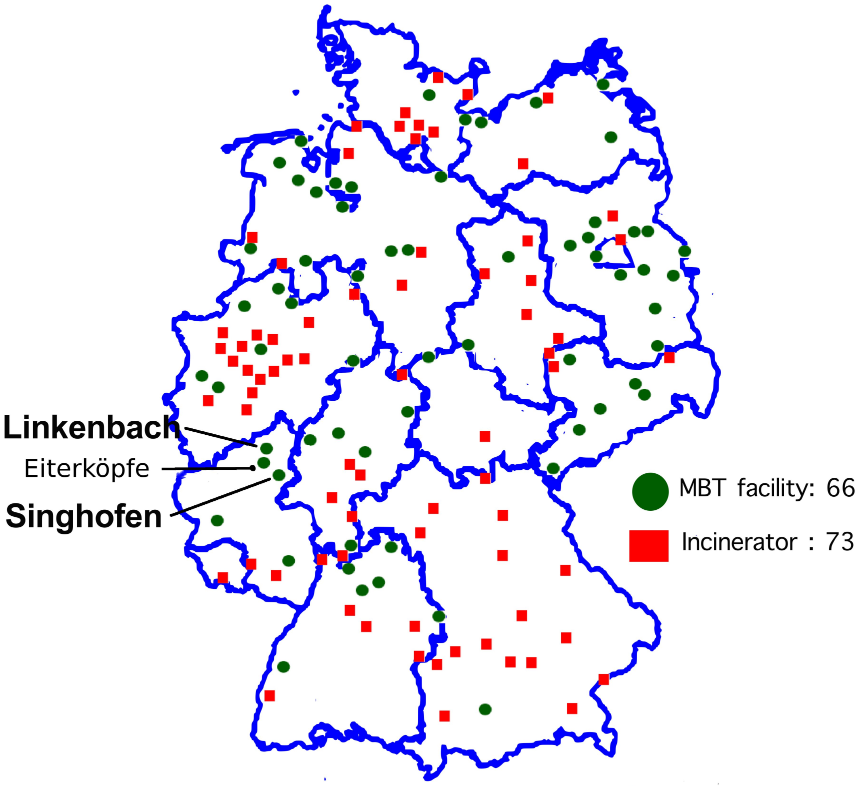


Figure 4.2: Locations of Linkenbach MBT plant, Singhofen MBT plant and Eiterköpfe landfill in Germany

MBT waste of Thailand is found only in Phitsanulok province, the lower northern part of the country. Chiemchaisri, 2006 reported 95 engineered landfills and 330 open dumps in Thailand. The engineered landfill requires huge land area which is very difficult to find in the urban area. Thailand has no rules of source separation for organic household waste.

Samples had been taken from a composting windrow immediately after the pretreatment process. Location of Phitsanulok landfill is shown in Figure 4.3.

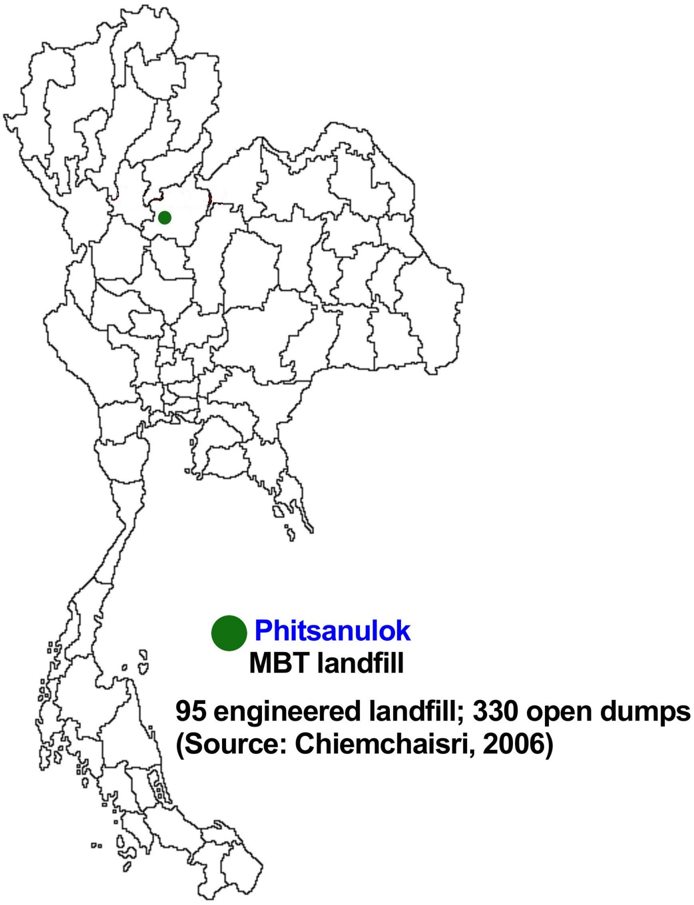


Figure 4.3: Location of Phitsanulok landfill in Thailand

4.1 Luxembourg

4.1.1 Fridhaff MBT plant

Waste and landfill management

Fridhaff has an average waste amount of 40,000 tons/year. The waste at the landfill contains 33% organic waste. Paper is the second component with 22% and plastics are 17% by weight. The group of plastics are mostly in the form of packaging waste of films, cups/bottles and blister packs/bottles.

Fridhaff MBT plant is organized and responsible by SIDEC since 1972. The landfill receives municipal solid waste from 57 communities in the region of Mersch, Redingen, Wiltz, Clervaux, Vianden and Befort. The number of population in this region is about 100,000 people.

SIDEC organizes the waste collections and runs the installations for stocking, recycling, treatment and the waste disposal. SIDEC collects residual waste from the various public waste bins in the volume of 60, 80, 120 and 240 liters. MSW is treated at the MBT plant. The MBT plant in Fridhaff operates since January 2006.

The landfill area covers about 7 ha. The total landfill body is divided into 4 phases:

1. The untreated waste was dumped in the eastern area of landfill without bottom sealing which was constructed before 1972. Since then there where no more significant gas emissions in this area. In the end of nineties this landfill area was restored.
2. The second phase of landfill area without basic sealing from the early seventies was backfilled until the year 1990 with untreated residual waste and bulky waste. The landfill body, which is on top of the connection between the first part and the intermediate sealing was covered in 2003 along the eastern slope to the edge with a 70 cm thick of clay surface seal. There are 3 drilled wells which are sinked to degasification of the landfill.
3. Untreated waste was dumped in the base sealed landfill section along the western part of the landfill from 1990 to 1998. A 70 cm thick layer of clay covered the landfill to protect it from weather up to the intermediate sealing of this landfill area.
4. From 2002 – 2004, intermediate sealing with asphalt lining was done. In the year 2004, the facilities of the container parks Fridhaff were built. The current waste

disposal area, with a 14 cm thick layer of asphalt (intermediate seal). The total volume capacity of the intermediate sealing is approximately 350,000 m^3.

Fridhaff MBT concepts

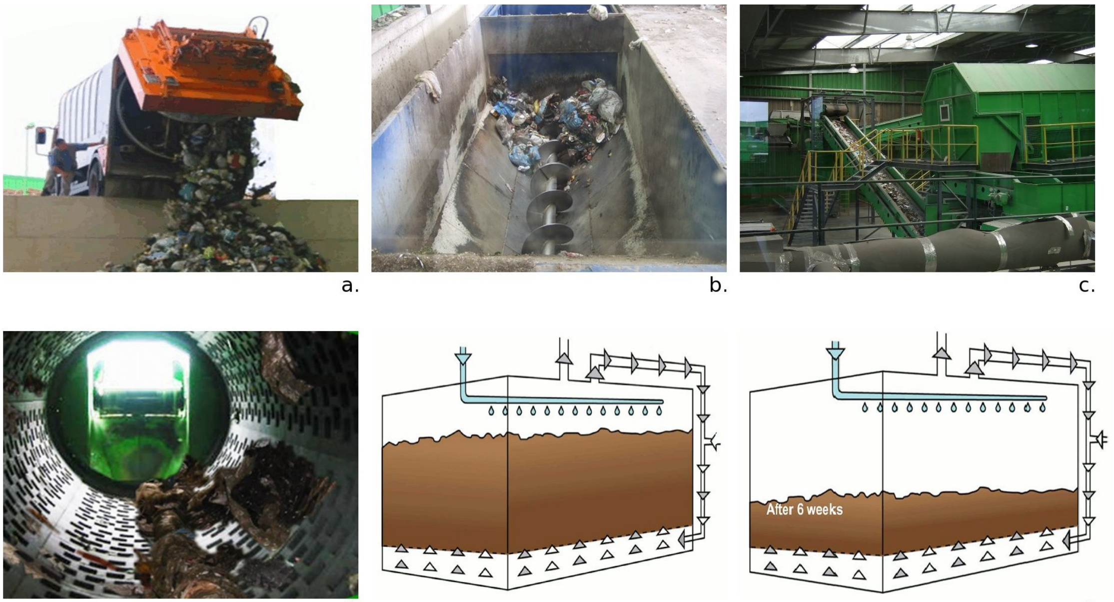
Mechanical stage

1. **Waste delivery:** Municipal solid waste is weighed and delivered to the acceptance dock. The reusable materials and hazardous materials are removed.
2. **Comminution:** The remaining materials are shredded by a shredder into defined particle sizes.
3. **Size screening:** The crushed material is transported on belt conveyors to the screening drum with the trommel sieve (ca.150 mm). The coarse fraction with high calorific potential material is sent through an electro – magnetic separator intended for metal – separation. Metals and high calorific materials for external thermal treatment (by incinerator in Leudelange) are separated. The fine fraction (< 150 mm) is mixed with leachate drained from the landfill, in a drum homogenizer, preparing the material for the upcoming biological treatment.

Biological stage

1. **Intensive biological treatment:** At the biological treatment installation, leachate and air fed micro-organisms break down the organic matter in 18 rotting concrete tunnels in a series with a volume of 750 m^3 of each. After 6 weeks of continuous treatment, MBT waste is landfilled.

Figure 4.4 presents the MBT processes of the Fridhaff MBT plant in Luxembourg. The present conditions of landfill at Fridhaff are presented in Figure 4.5 and Figure 4.6.



a. b. c.

d. e. f.

Figure 4.4: Mechanical and biological treatment of Fridhaff MBT plant, Luxembourg: a) waste is delivered to the acceptance area; b) closed plastic bags are opened by drill; c) crushed material is transported on belt conveyer; d) trommel sieve with size ca. 150 mm; e) a drawing of aeration rotting tunnel leachate circulation for beginning biological treatment; f) a drawing of aeration rotting tunnel for waste after 6 weeks

Figure 4.5: Condition of disposal site at Fridhaff-Diekirch

Figure 4.6: Landfill covered with asphalts at Fridhaff-Diekirch

4.1.2 Muertendall landfill

Muertendall landfill is organized and responsible by SIGRE since 1979. Landfill receives waste from 25 communities in the region of Grevenmacher, Remich and Echternach. The number of population in total was 55,228 people (2006) [Wikipedia.org, 2009b]. The amount of waste is about 100 – 120 tons / day. The waste contains organic waste 30.71%, paper 24.32%, and plastics 17.75% by weight [Schmit and Mathieu, 2005].

The landfill area is covered about 7.2 ha in the beginning of 1979. The closing of the landfill was done in 1991 with the load capacity of 300,000 m^3. In 1992, the new landfill was built. From 1995 – 2000, the landfill was designed with constructional plans for 3 phases.

1. In the first phase, the landfill area was prepared from 1995 – 1996. The north part of the landfill was designed for two parts, one was for placing the old waste and another was for new waste.
2. During the second phase, the landfill area was prepared from 1997 – 2000 for the rest of old waste.
3. The third phase is planed for a construction in summer 2009 for new waste.

Muertendall landfill is a type of open dumping landfill with liner and leachate collection zone. Leachate from the closed landfill and active landfill have been collected together. A higher space is needed in the landfill for the rotting process. In general, composting heap is constructed with the approximate of 2 to 3 meters height of waste on the landfill. The length of the composting heap does not exist as the space is limited. It is possible to spend the whole area for the waste. In order to accelerate the biological process, some slot pipes have been inserted between the waste of the composting heap. There are no materials or bio-filter materials to cover the waste body to avoid from smells and vermin. Besides, some part of the landfill is used for composting bio-fertilizers (only wood and leaves). They produce and sell regularly bio-fertilizers products. Moreover, the landfill earns income from buying and selling recyclable materials from private households or companies. Those recyclable materials are stocked at the separated sections before selling to the recycling plants.

Muertendall does not have the MBT process on the landfill site. The mechanical pre-treatment for MSW is done outside the landfill in a pressing truck and trommel during transport to the landfill (data from interview with Mr.Zens). The operational practice for waste treatment by workers is simply delivering and dumping the waste into the landfill. Compaction is given by the caterpillar or excavator after dumping.

Figure 4.7 presents the condition of Muertendall landfill.

Figure 4.7: Condition of disposal site at Buchholz-Muertendall

4.2 Germany

4.2.1 Linkenbach MBT plant

Waste and landfill management

Linkenbach has an average waste amount of 90,000 tons/year or in average 340 tons/day. According to Federal Environment Agency, organic waste is about 30%, paper is 24% by weight. Recyclable materials are sorted out mostly at the producer level.

The mechanical biological treatment technology at Linkenbach was introduced in 1998. The Linkenbach MBT plant is one of municipal solid waste treatment facilities in the region of Rhineland-Pfalz, western Germany. The waste is 40% from Neuwied/Rhein district, 25% from Bad Kreuznach district, 15% from Rhein-Hunsrück-Kreis district and 20% from Mayen-Koblenz. At the mechanical treatment, there are a crushing and additional units of screening lines. The biological treatment is divided into two parts, that are an intensive indoor composting heaps and an open installation for composting heaps with turning machine. Total period of biological treatment is 15 weeks. Treatment of exhaust gas is operated by the regenerative-thermal treatment of exhaust gas system. The Linkenbach MBT plant pretreats the municipal solid waste from its own region and the Eiterköpfe district and sent them back to the Eiterköpfe landfill.

The responsible area covers about 626.80 km^2. This areas included 3 transfer stations at Neuwied, Linz and Linkenbach districts.

In 1995, the decision of waste treatment for the four districts on the right part of Rhineland-Palatinate was agreed. The landfill body was filled with 70,900 m^3 of waste for the first phase. The capacity volume for the rest of phase 2 was about 109,000 m^3 in the year 1998. Until 2004, the household and the household-like industrial wastes from the Neuwied district were treated in the plant. Adapting the available MBT to the status of the Federal Emissions Regulations and extending it to a maturation hall was managing the construction for the MBT building and concern facilities during 2002 – 2006. There were the composting hall, incinerated process air facility and waste delivery hall, preparation place for Mechanical process. The plan for performance monitoring after extension landfill and adaptation of the MBT plant is being done during 2006 – 2010. The leachate collection system was installed with the leachate treatment plant. Leachate is reused in the homogenization of the mechanical treatment.

Linkenbach MBT concepts

Mechanical stages

1. **Waste delivery:** Municipal solid waste is weighed and delivered to the delivery hall. The reusable materials and hazardous materials are removed.
2. **Comminution:** The remaining materials are shredded by a shredder into defined particle sizes.
3. **Size screening:** The crushed material is transported on belt conveyors to the screening drum with the trommel sieve (ca.80 mm). The coarse fraction with high calorific potential material is sent through an electro – magnetic separator intended for metal – separation. Metals and high calorific materials for external thermal treatment are separated. The fine fraction < 80 mm is mixed with leachate drained from the landfill, in a drum homogenizer, preparing the material for the upcoming biological treatment.

Biological stages

1. **Biological first treatment:** The homogenized residual waste after mechanical treatment is delivered to the closed installation composting with mobile turning equipments for adding air into composting heaps. The intensive rotting treatment lasts for about 3 weeks.
2. **Biological second treatment:** At the second rotting process, the material from the intensive rotting process is placed at an open installation. The waste is treated at the biological second treatment for 12 weeks. The heaps are turned with a turning machine in every 2 weeks. Later, the MBT output is sent to the landfill.

Figure 4.8 presents the MBT process of the Linkenbach MBT plant. The condition of Linkenbach landfill with their MBT material can be seen in the Figure 4.10.

4.2.2 Singhofen MBT plant

Waste and landfill management

Singhofen has an average waste amount of 120,000 tons/year or in average 480 tons/day. According to Federal Environment Agency, organic waste is about 30%. Plastics are about 13%. Recyclable materials are sorted out mostly at the producer level.

The landfill is operated by the municipality of Rhein-Lahn.

In 1974, the municipal solid waste management at Singhofen was initiated. In that year, the sanitary landfill was built and covered an area of 40 ha with the volume of 7 Million m^3. At present MBT material, soil and more from the responsible is processed in the dumping site Singhofen. The mechanical biological treatment technology in Singhofen was introduced in 2000. The operational system of solid waste treatment is rather simple and short. Singhofen has a similar experience for the mechanical treatment step like Linkenbach. The residual households waste is pre-treated in three steps mechanically (shredding, size screening and homogenization) and is prepared thus for the biological treatment.

Total biological treatment is about 15 weeks. The process air from the mechanical and the biological processes is cleaned and burned. The biogas which originates from the rotting process of bio-degradable material in the landfill is used in the process air. Since 2007, Eiterköpfe landfill (disposal partner) which is located in Koblenz, has given their residual waste to the Singhofen MBT plant for treatment. During the year 2005 – 2007, the covering plastic materials were used everyday for the landfill. However, a result from the test at landfills showed that a stream of air from the biological process can not evaporate and that increases the amount of water. Therefore, the operational practice of covering materials was given up since February 2007 (data from interview with Mr.Warnstedt).

On the other hand, the Singhofen MBT plant operated the bio-waste separately from the residual waste. The bio-waste is separated in a coarse fraction and fine fraction. The coarse fraction is dried and then used externally for energy source. The fine fraction is composted. Leachate is collected and treated at the leachate treatment plant at the landfill. There are several groundwater controlling stations around the landfill.

Condition of Singhofen landfill with their MBT material can be seen in Figure 4.11.

Singhofen MBT concepts

Mechanical stages

1. **Waste delivery:** Municipal solid waste is weighed and delivered to the inside receiving point. The reusable materials and hazardous materials are removed.
2. **Comminution:** The remaining materials are shredded by a shredder into defined particle sizes.
3. **Size screening:** The crushed material is transported on belt conveyors to the screening drum with the trommel sieve (ca.80 mm). The coarse fraction with high calorific potential material is sent through an electro – magnetic separator intended for metal – separation. Metals and high calorific materials for external thermal treatment are separated. The fine fraction < 80 mm is mixed with leachate drained from the landfill, in a drum homogenizer, preparing the material for the upcoming biological treatment.

Biological stages

1. **Biological first treatment:** the Singhofen plant uses 28 composting tunnels with floor aeration for the biological first treatment step. The material is weekly moved into the next tunnel during 5 weeks of the process.
2. **Biological second treatment:** At the biological second treatment step, the material is moved to the open installation for 9 weeks. Later, the MBT output is sent to landfill.

Figure 4.8: Mechanical and biological treatment of Linkenbach MBT plant in Germany: a) waste is delivered to the delivery hall; b) a small excavator put waste in the cutting machine/shredder; c) crushed material is screened inside screening drum with trommel sieve ca. 80 mm; d) high calorific potential material is separated and sent to thermal treatment; e) intensive rotting process at closed installation; f) second rotting process at the open installation

4.2.3 Eiterköpfe landfill

Eiterköpfe landfill is a type of MBT landfill. The Eiterköpfe Central landfill is situated in the District of Mayer-Koblenz, north-west of Koblenz of the Rheinland-Pfalz. The landfill area is located in a volcanic cavity. The landfill has been expanded since the 1980's and is using for a municipal solid waste. It has a capacity of about 11.5 million m^3 for depositing household and bulky waste, sewage sludge and industrial waste. The Districts of Mayen-Koblenz and Cochem-Zell as well as the city of Koblenz have joined together to form the 'Deponiezweckverband Eiterköpfe' or (DZV). The amount of waste is 258,069 ton/year (2007). The Eiterköpfe landfill does not have the MBT treatment process. Eiterköpfe sends their waste to the Linkenbach and the Singhofen MBT plants where the waste is pretreated and waste after treatment is dumped at the Eiterköpfe landfill. Figure 4.9 presents the condition of Eiterköpfe landfill with their MBT material.

Figure 4.9: Condition of diposal site at Eiterköpfe

Figure 4.10: Condition of disposal site at Linkenbach

Figure 4.11: Condition of disposal site at Singhofen

4.3 Thailand

4.3.1 Phitsanulok landfill

Waste and landfill management

The city of Phitsanulok has an average waste amount of 100 tons/day for disposal. Recyclable materials of more than 95% are sorted out at the producer level or during the collection. The waste at the landfill site is rich in organic material [Schoell, 2006]. It is approximately 60% of the total waste. Plastic bags are the second most component. It is approximately 20%.

Phitsanulok province has one disposal site for MSW. It is organized by the municipality of Phitsanulok. All waste management tasks such as collection, transport and disposal are at present performed by own staff from the municipality and no contract with any private operator exists. The landfill is located in Bangrakam district which is away 40 km from the city. The sanitary landfill was introduced in 1999, and later the application system of pre-treated process for solid waste was conducted by a German company. At present, the landfill receives the residual household waste from 27,000 households in Phitsanulok municipality. The number of population in all total is approximately 90,000 people. The whole landfill area covers a total of 230 Rai[2] (36.8 ha). The landfill area covers 40 Rai (6.4 ha). It is divided into 4 cells, each cell covers for 10 Rai (1.6 ha). The cell 1 and 2 are closed areas and cell 3 and cell 4 are active areas. Individual disposal cell has a dimension of about 100 m x 100 m. A storm water basin and a leachate collection pond occupy a large area. No treatment system exists for the leachate except recycling by spraying in the active cell [Schoell, 2006].

The MBT technology in Phitsanulok was introduced in 2001. The residual waste is collected and transported to the landfill by a pressing truck. The waste is treated with low technique and low financial investment. The recyclable materials are removed by the recyclable separation / source separation system which is the only successful case in Thailand. Besides, waste pickers and /or Saleng at the landfill also sort the recyclable waste and sell them to private sectors in waste recycling business. However, many plastic bags remain in the waste composition.

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[2] Rai is a Thai unit of area used for measuring land area, equal to 1600 square meters (40 m x 40 m)

Phitsanulok MBT concepts

Mechanical stages

1. **Waste delivery:** The municipal solid waste is collected by a pressing truck to reduce the volume and transported to the landfill site. The waste pickers removed recyclable materials out from the whole waste.
2. **Comminution:** The fresh waste is shredded to reduce its size and homogenized at the mechanical treatment process by the mobile rotary drum. Inside the drum, sprockets are installed to open the closed plastic bags. There is no trommel screening drum to separate the high calorific potential material and metals.

The Phitsanulok, Thailand has no sieving at the mechanical stage, compared to the Fridhaff, Luxembourg and Singhofen, respectively Linkenbach MBT plants, Germany.

MBT process of Phitsanulok, Thailand presents in Figure 4.12. Figure 4.13 presents windrows covered with coconut husks at the Phitsanulok landfill. Figure 4.14 presents the condition of Phitsanulok landfill.

Biological stages

1. **Biological treatment:** At the biological treatment, the waste is heaped to windrows onto a layer of wooden pallets on the landfill. The passive aeration is implemented by placing many slot pipes according the chimney system.

   The composting windrow is covered with coconut husks as bio-filter, in order to avoid odor and vermin, without turning for 9 months of the degradation process.
2. **Size screening:** After 9 months of biological treatment, the MBT materials are sieved into 3 parts (< 10 mm, $10 - 40$ mm, > 40 mm) for further material utilization.

MBT samples from Phitsanulok, Thailand had been taken from the composting windrow immediately before the size screening.

The characteristics data of start date, composting processes, landfilled waste, volume and residents of all three MBT places are summarized in Table 4.1.

Figure 4.12: Mechanical and biological treatment of Thailand: a) waste is put inside the mobile rotary drum to open closed plastic bags; b) wooden pallets and slot pipes are placed on the ground of landfill; c) the windrows of waste are constructed by an excavator; d) constructed windrows are covered with coconut husks as bio-filters; e) non turning windrows for 9 months; f) after 9 months, material is sieved for further utilization

Figure 4.13: Windrows covered with coconut husks

Figure 4.14: Condition of disposal site during biological treatment at Phitsanulok

Table 4.1: Data of start date, composting processes, landfilled waste, volume and residents of the study areas

Name	City/ Country	Start-up	Processes	Waste	t/yr	Residents
Muertendall	Flaxweiler/ LU	1979	not found MBT process	MSW, biowaste	25,000	55,228
Fridhaff	Diekirch/ LU	begin 2006	shredding, screening (ca.150 mm), magnetic separator, leachate recirculation aeration 18 – tunnel rotting duration (6 weeks)	MBT waste biowaste	40,000	100,000
Linkenbach	Neuweid/ DE	1998	shredding, creening (ca. 80 mm) magnetic separator indoor aeration composting heaps duration (3 weeks) outdoor aeration rotting heaps duration (12 weeks) turning machine	MBT waste, biowaste	90,000	600,000
Singhofen	Rhein-Lahn/ DE	2000	shredding, screening (ca. 80 mm) magnetic separator aeration 28 tunnel composting (5 wks) outdoor aeration rotting (9 wks)	MBT waste, biowaste	120,000	134,200
Eiterköpfe	Koblenz/ DE	1980	not found MBT process	MBT waste, sewage sludge industrial waste	258,069	
Phitsanulok	Phitsanulok/ TH	end 2001	shredding mobile rotary drum passive aeration chimney system trapezoidal windrow composting duration (9 months) covered with coconut husks	MBT waste	40,000	100,000

Chapter 5

Results

5.1 Physical – Chemical surveys of total MBT samples

5.1.1 Size fraction analysis and particle size distribution

Although Muertendall, Luxembourg does not have the MBT processes, some physical – chemical characteristics of the collected samples needed to be tested to determine the type of samples. The data on particle size analysis is presented in Figure 5.1.

The graph was drawn to see the comparison of size fraction analysis. The Muertendall sample 1 was an old MSW which was redeposited after more than 20 years. The waste sample was already highly degraded. The large size $>$ 40 mm was found to be 1% by weight. In contrast, the Muertendall sample 2 and 3 showed higher percentage of the large size $>$ 40 mm. High calorific waste and non-degradable (plastics) waste materials were most often found in the samples. Maximum particle sizes of the waste was 1000 mm. Figure 5.2 illustrates a large piece of plastic in the waste sample which was deposited for 6 – 10 years with a diameter of 1000 mm. In addition, many extreme large piece of thick plastics, clothes, metals, leather, even used shoes, used jackets were also found in samples (see Figure 5.3). These materials should be avoid dumping on the landfill. They should not be found in the pretreated waste. Samples from the Muertendall did not appear to reach the pretreated waste standard according to size per piece allocation (maximum particle size 40 – 60 mm). This particle size analysis proved that is not standard MBT material even if it was treated with a low pretreatment technique.

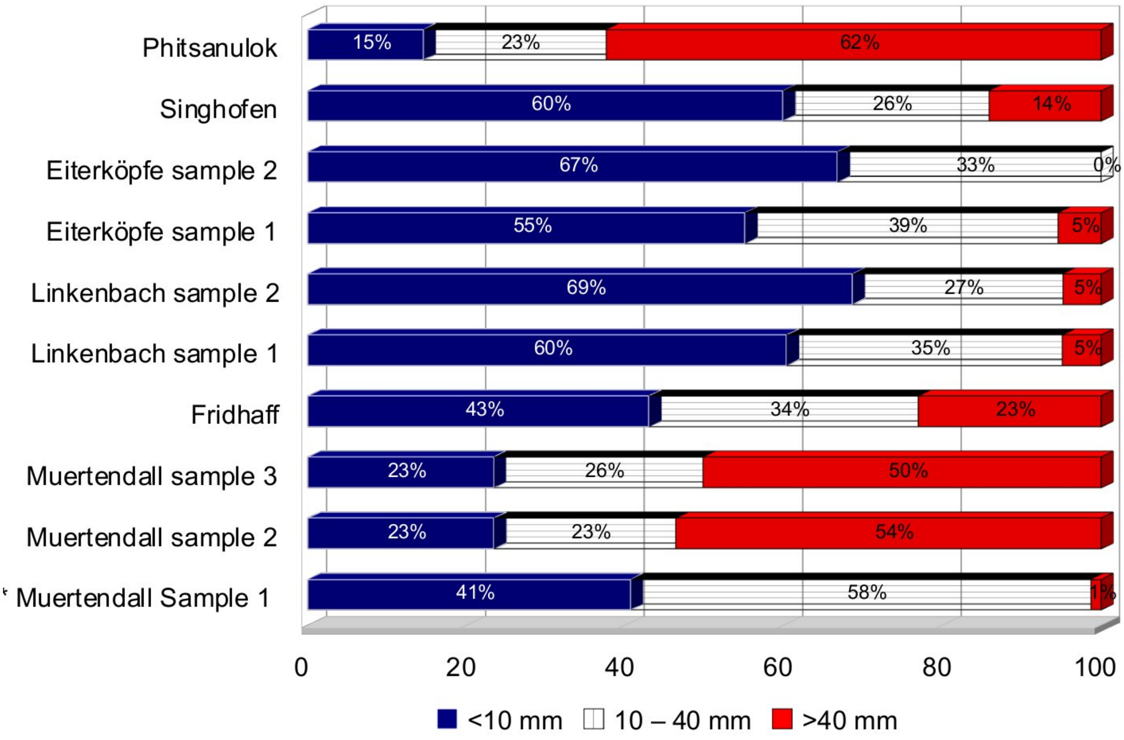

Figure 5.1: Three size fractions (weight %) comparison of the samples from study areas

In comparison with the Phitsanulok waste after pretreatment, there the large particle size > 40 mm was found to be 62% by weight which showed also a high proportion. The small particle size was found to be in average 15% by weight. However, the maximum particle size of waste is rather smaller than Muertendall (all waste was found to be < 100 mm). The large particle size was found only due to plastic bags. There was no recycling of material.

Particle size < 10 mm was found as a majority group in samples from the Singhofen, Eiterköpfe and Linkenbach from Germany. They showed a similar high proportion of particle size < 10 mm. It was more than 50% by weight. The proportion of small particle size in each sample is different due to different composting periods of samples. In comparison, the Fridhaff waste sample after treatment from Luxembourg showed a lower proportion of particle size < 10 mm (43% by weight).

Result of size fraction analysis shows that samples from Muertendall landfill which had been deposited for 10 years showed a high proportion of large size > 40 mm of 54% by weight. Due to the long time of rotting period and the maximum size of waste, it is obviously that samples were not pretreated waste. With this reason, samples from the Muertendall landfill were not used for discussion.

Figure 5.2 and Figure 5.3 present very large pieces of non degradable materials which were found in the samples from the Muertendall landfill. The materials can be used for thermal recycling or refuse derived fuel (RDF).

Figure 5.2: Very large piece of plastic in waste samples from the Muertendall

Figure 5.3: Non degradable waste (used shoes, jackets, leather and thick plastics) found in waste samples from the Muertendall

For MBT waste from Germany only one example for size fraction analysis is shown for a sample from the Singhofen MBT plant. Results from the Fridhaff MBT plant show an example from Luxembourg. For the following comparison, all further tests were done only with MBT samples from the Singhofen, Fridhaff and Phitsanulok.

The summarized data of size fraction is shown in Figure 5.4. Appearance of MBT material after pretreatment from the three countries is shown in Figure 5.5. Figure 5.6 presents photos of the sieved MBT samples for three groups size fraction analysis.

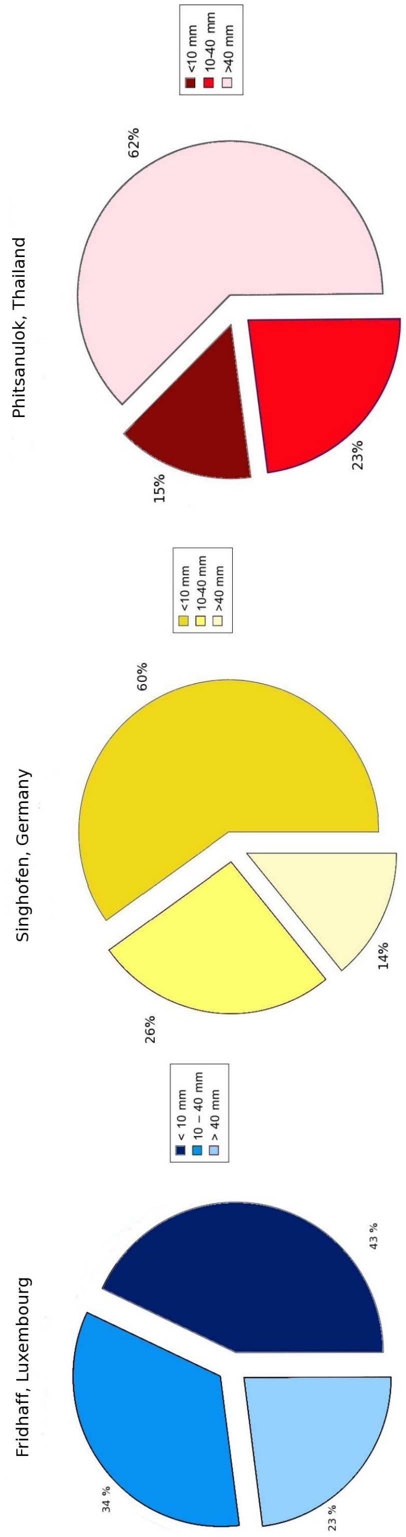

Figure 5.4: Graphical data of three size fractions of MBT material analysis

Fridhaff, Luxembourg

Singhofen, Germany

Phitsanulok, Thailand

Figure 5.5: MBT material (not sieved) after pretreatment from study areas

Figure 5.6: Images of three size fractions of MBT material analysis: a) small size < 10 mm of sample from Singhofen, Germany; b) medium size of 10 – 40 mm of sample from Singhofen Germany; c) large size of > 40 mm of sample from Singhofen Germany; d) small size < 10 mm of sample from Fridhaff Luxembourg; e) medium size of 10 – 40 mm of sample from Fridhaff Luxembourg; f) large size of > 40 of sample from Fridhaff Luxembourg; g) small size < 10 mm of sample from Phitsanulok Thailand; h) medium size of 10 – 40 mm of sample from Phitsanulok Thailand; i) large size of > 40 mm of sample from Phitsanulok Thailand

Particle size distribution of whole sample

Particle size is an important parameter for the hydraulic property of the waste samples. The samples were screened into 12 fractions: > 90 mm, 40 – 90 mm, 30 – 40 mm, 20 – 30 mm, 10 – 20 mm, 8 – 10 mm, 6.3 – 8 mm, 4 – 6.3 mm, 2 – 4 mm, 1 – 2 mm, 0.5 – 1 mm, and < 0.5 mm by dry sieving method. The method of dry sieving is a suitable technique for the MBT material.

We know the maximum grained-size (Germany = 80 mm, Luxembourg = 150 mm and Thailand has no sieving) of particles and the exact composition of material before testing. A correlation between percent weight passing and sieve sizes was drawn in a semi-logarithm scale. Figure 5.7 shows a result of comparative particle size distribution curves of the MBT samples from the study areas. The particle size distribution curves of MBT samples from the three countries are different. An increasing trend of fine particle size is found in the order: Thailand < Luxembourg < Germany.

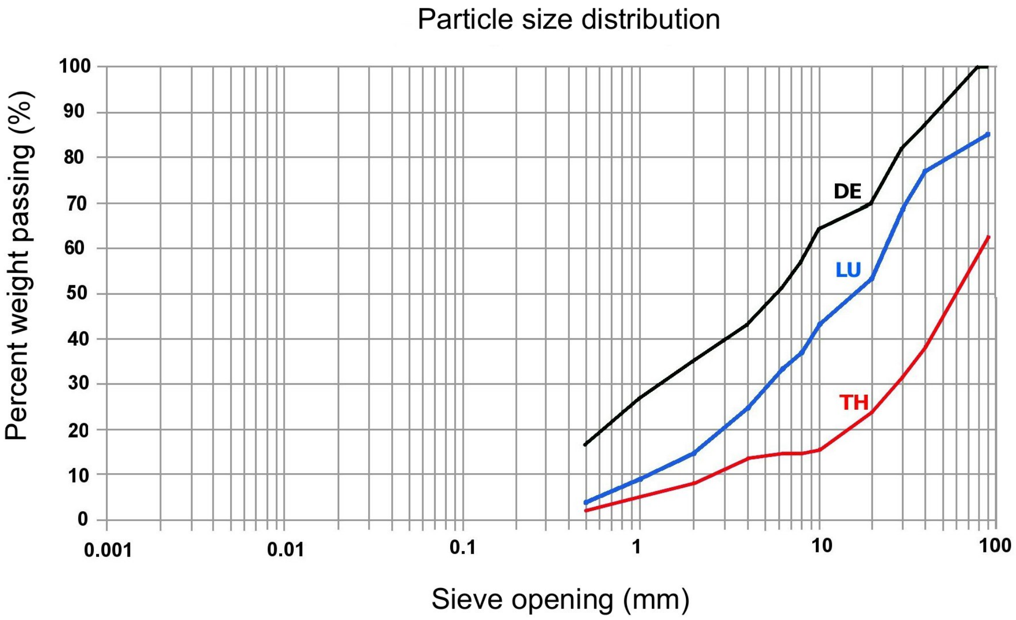

Figure 5.7: Particle size distribution curves of MBT materials

Particle size distribution of small size

If we look only at the small size particle < 10 mm (the results are shown in Figure 5.8), the particle size distribution curves show an opposite trend. The coarse particle size for particles < 10 mm increases in the order of Thailand $>$ Germany and Luxembourg.

This is important as the geotechnical tests were only done with particle size < 10 mm. This is because the large particle sizes of MBT samples could not be used in the geotechnical apparatus normally used for soil mechanical analysis.

Grain size classification

The grain size classification after Gladstone 1992 is:

20 – 60 mm (coarse gravel), 6 – 20 mm (medium gravel), 2 – 6 mm (fine gravel), 0.6 – 2 mm (coarse sand), 0.2 – 0.6 mm (medium sand), 0.06 – 0.2 mm (fine sand). Based on this classification, the MBT samples can be classified as coarse gravel to fine sand. The calculation of gradation (see appendix B) of these material classifies MBT material as poorly sorted (wide ranges of different sizes). (C_u Luxembourg = 22.72; C_u Germany = 15.38 and C_u Thailand = 30.76).

The histogram of mean mass percentage versus particle size fraction < 10 mm is shown in Figure 5.9. The fine particles < 4 mm represent the majority of the MBT small particle sizes in all three countries. The mean mass percentages of the fine particle < 4 mm was 57% (Luxembourg), 72% (Germany) and 83% (Thailand), respectively.

The highest mean mass percentage was found for materials of size 2 – 4 mm in samples from all countries. The mass percentages of particles 2 – 4 mm in samples from study areas ranged from 23 to 26% by weight.

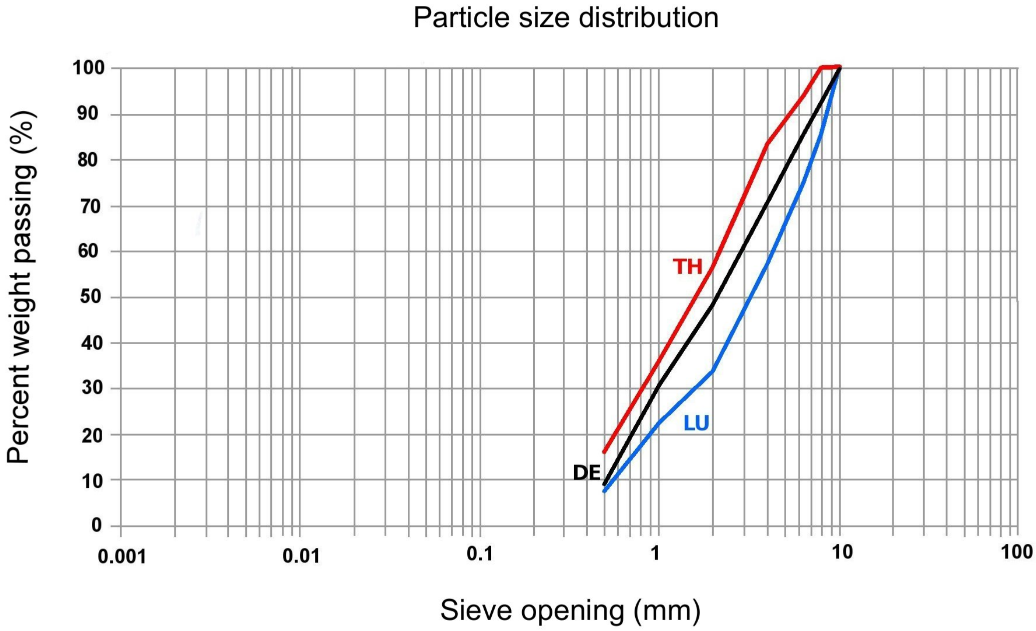

Figure 5.8: Particle size distribution curves of MBT material (<10 mm)

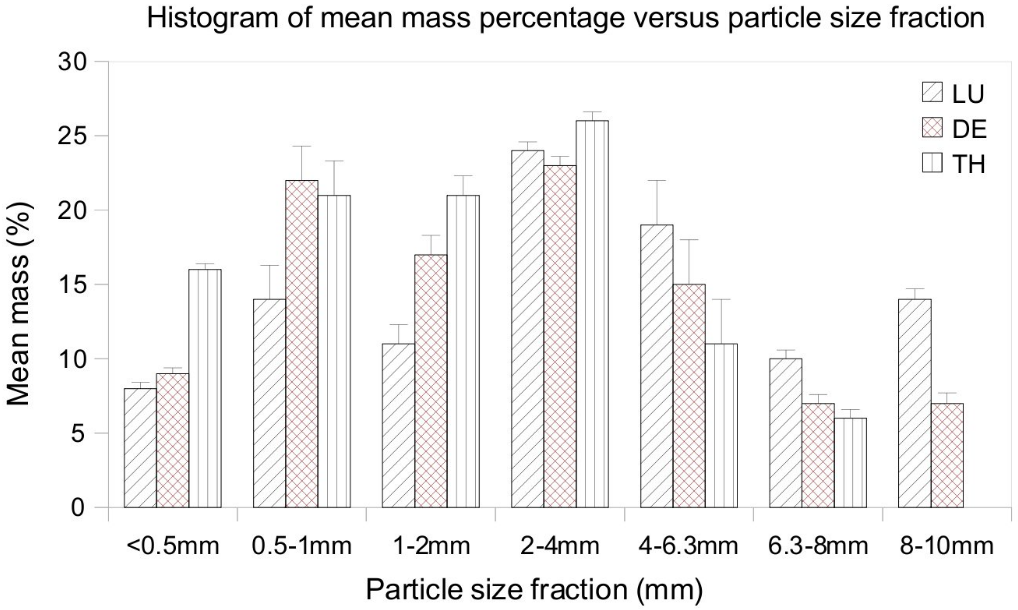

Figure 5.9: Mean mass percentage versus grain size fraction of particles (<10 mm)

5.1.2 Composition

The waste composition of each separated group was characterized by visual identification (human eyes). Each item of waste was weighed and calculated in percentage by weight.

Table 5.1 lists the 27 types of items which were found and categorized into 6 main categories:

Table 5.1: 6 mains categories and 27 item categories used for composition details

Item	No.	Details
Organic	1	Organic waste
	2	Piece of wood
	3	Bone
Plastics	4	PE bottles
	5	PET bottles
	6	Good packages
	7	Super bags
	8	Other plastics
	9	Foil
	10	Foam
Glass	11	Transparent glass
	12	Brown glass
	13	Green glass
	14	Other glass
	15	Ceramics
Paper	16	White paper
	17	Paper cartons
Metal	18	Steel cans
	19	Aluminum
Others	20	Fiber and textiles
	21	Napkins
	22	Rubber and leather
	23	Stone
	24	Batteries
	25	Sponges
	26	Corks
	27	Lights

The small size with a diameter of < 10 mm has organic waste as a majority part. The small size fraction from Phitsanulok and Singhofen were homogenous organic (100% by weight for Phitsanulok, Thailand and 98% by weight for Singhofen, Germany). Longer period of aerobic composting of Phitsanulok, Thailand transforms all easily degradable organic waste (mainly food waste). Beside organics, small crushed plastics and ceramic fragments (28%) were found in the small size sample from Fridhaff, Luxembourg. The medium size with a diameter of 10 – 40 mm contains various kind of items. The medium size fraction from Phitsanulok still has 63% by weight of organics. The medium size fraction from Fridhaff has 44% by weight of plastics. The medium size fraction from Singhofen has 58% by weight of glass/ceramic. The large size with a diameter of > 40 mm of all three MBT samples has plastics as a majority part. Data of composition analysis of MBT samples in percentage by weight from Fridhaff, Singhofen and Phitsanulok are presented in Tables 5.2, Tables 5.3 and Tables 5.4, respectively.

Fridhaff (Luxembourg)

Table 5.2: Composition of MBT samples in percentage by weight from Fridhaff

Items	< 10 mm	10 – 40 mm	> 40 mm
Organics	72	0	0
Plastics	3	44	75
Glass/ceramic	17	30	17
Paper	0	11	0
Metals	0	6	0
Others	8	9	8
Total	100	100	100

Singhofen (Germany)

Table 5.3: Composition of MBT samples in percentage by weight from Singhofen

Item	< 10 mm	10 – 40 mm	> 40 mm
Organics	98	0	3
Plastics	2	29	71
Glass/ceramic	0	58	26
Paper	0	0	0
Metals	0	0	0
Others	0	13	0
Total	100	100	100

Phitsanulok (Thailand)

Table 5.4: Composition of MBT samples in percentage by weight from Phitsanulok [Data of Naresuan University, 2006]

Item	< 10 mm	10 – 40 mm	> 40 mm
Organics	100	63	7
Plastics	0	18	81
Glass/ceramic	0	13	10
Paper	0	2	0
Metals	0	4	2
Others	0	0	0
Total	100	100	100

Table 5.5 presents composition of waste from Muertendall. Table 5.6 presents composition of waste samples from Eiterköpfe and Table 5.7 presents composition of waste samples from Linkenbach.

Muertendall (Luxembourg)

Table 5.5: Composition of waste in percentage by weight from Muertendall

Items	% by weight	Dry weight (%)
Organics	34.62	18.66
Plastics	20.36	19.51
Glass/ceramic	6.94	6.76
Paper	16.82	15.81
Metals	4.15	4.01
Others	17.11	15.37
Total	100.0	80.12 + 19.88 water

Eiterköpfe (Germany)

Table 5.6: Composition of MBT samples in percentage by weight from Eiterköpfe

Item	Sample 1			Sample 2		
	< 10 mm	10 – 40 mm	> 40 mm	< 10 mm	10 – 40 mm	> 40 mm
Organics	98.5	41	27	100	40	0
Plastics	1	14	26	0	17	0
Paper	0	0	0	0	0	0
Metals	0	0	0	0	0	0
Glass/ceramic	0.5	31	0	0	18	0
Others	0	14	47	0	25	0
Total	100	100	100	100	100	0

Linkenbach (Germany)

Table 5.7: Composition of MBT samples in percentage by weight from Linkenbach

Item	Sample 1			Sample 2		
	< 10 mm	10 – 40 mm	> 40 mm	< 10 mm	10 – 40 mm	> 40 mm
Organics	100	48	0	100	41	0
Plastics	0	10	100	0	23	100
Glass/ceramic	0	26	0	0	36	0
Paper	0	0	0	0	0	0
Metals	0	0	0	0	0	0
Others	0	16	0	0	0	0
Total	100	100	100	100	100	100

5.1.3 Additional Physical – Chemical Characteristics

Table 5.8 presents the results of water content, pH-value and TOC solid (%) of all samples.

Water content

The determination was based on the three groups of the sieved particle size. The content of water in waste sample increased with decreasing of particle size. The sample from Fridhaff, Luxembourg was found to have the highest percentage of water content (in average 39% by weight), due to the short composting period. The samples from Singhofen, Germany and Phitsanulok, Thailand were found to have less water content in average 27% by weight and 25% by weight, respectively.

pH-value

The three groups of the sieved particle size have very similar pH-values. There was not a significant difference in the pH-value of samples from the three countries. The pH value of MBT samples was found to be in average 8.0.

Total Organic Carbon (TOC)

The small size < 10 mm was found to have a higher percentage of TOC than the medium and large sizes. This is due to the higher content of organics in the smaller size fraction. The MBT sample from Thailand did show the lowest percentage of TOC (in average 7.45% by weight) because of the low amount of grain sizes < 10 mm.

Table 5.8: Physical – Chemical characteristics of three size fractions analysis

Parameters	**Luxembourg**				**Germany**					**Thailand**
	MD			**FH**	**EK**		**LB**		**SH**	**PL**
	I	II	III	I	I	II	I	II	I	I
Disposed duration	>20 yrs[a]	6-10 yrs[b]	1-2 yrs[c]	6 wks	20 wks	40 wks	25 wks	35 wks	15 wks	1 yr
1. Water content (%)										
a. < 10 mm	45	54	55	44	23	41	40	69	31	31
b. 10-40 mm	39	55	50	40	15	40	31	48	28	27
c. > 40 mm	14	16	28	33	12	-	26	31	22	16
Average water content	33	42	44	39	17	41	33	50	27	25
2. pH-value										
a. < 10 mm	8.9	7.8	7.6	8.36	8.29	8.75	8.43	8.24	8.28	8.0
b. 10-40 mm	8.6	7.61	7.83	8.35	8.22	8.91	8.4	8.04	8.14	8.3
c. > 40 mm	8.5	7.5	7.8	8.10	8.05	-	8.15	8.07	8.09	7.7
Average pH-value	8.7	7.64	7.74	8.28	8.19	8.83	8.33	8.12	8.17	8.0
3. TOC solid (%)										
a. < 10 mm	NA	NA	NA	12.50	14.74	20.3	15.16	19.15	11.3	8.47
b. 10-40 mm	NA	NA	NA	11.5	11.8	10.6	13	11.8	10.6	8.1
c. > 40 mm	NA	NA	NA	11.4	11	-	12	15.7	9.5	5.8
Average TOC (%)	NA	NA	NA	11.8	12.5	15.45	13.38	15.55	10.5	7.45

---

[a] redeposited waste

[b] not standard pretreated waste

[c] not standard pretreated waste

5.2 Geotechnical tests

5.2.1 Compaction test

Figure 5.10 presents the comparison of compaction curves of MBT materials < 10 mm in diameter from the study areas. Based on the result, the maximum dry density of MBT material varied with content of organics. The compaction curve of sample from Luxembourg shows a slow increase on the dry side of optimum water content. The sample had more proportion of inorganic material. Plastic and inert components in the sample were light, thin and elastic, difficult to be compacted and became dense material. These small fraction has quite a large surface area. The optimum water content is relatively high. The material took up more water than other samples. The water can be stored above the thin plastic sheets, in particular horizontally oriented sheets.

The compaction curve for the German sample shows a quick increase of dry density on the dry side of the optimum water content. The sample material from Germany had about 2% by weight of the inorganic fraction. In this case, the sample showed a higher maximum dry density and higher optimum water content than the Thai sample. The small size of sample from Germany consisted of mainly organics (98%). The small particle size of compost can fill easily in small void spaces between plastic fragments during the compaction. It may increases also the cohesive forces between particles.

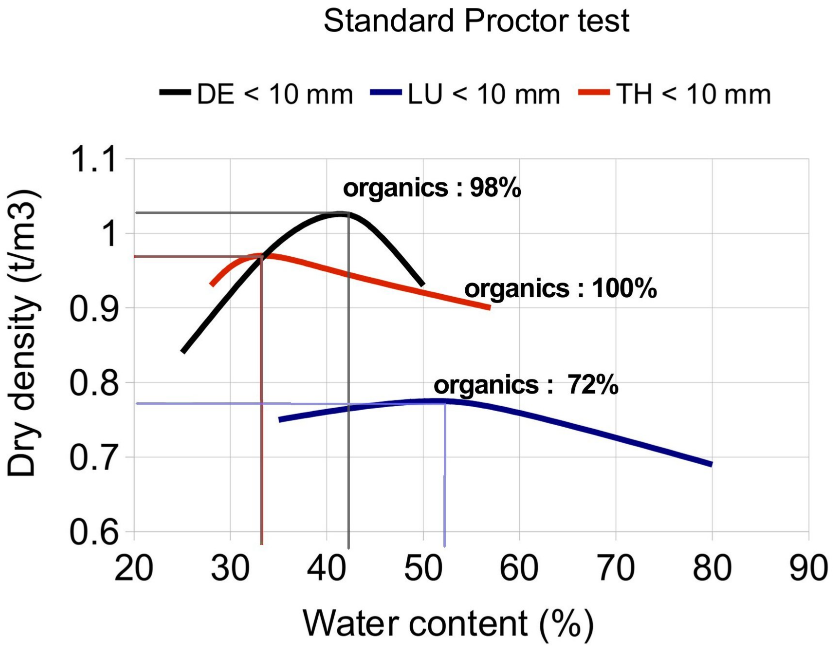

Figure 5.10: Proctor density on MBT samples < 10 mm

Proctor density

- 1.04 t/m^3 ±0.03 (Germany)
- 0.98 t/m^3 ±0 (Thailand)
- 0.78 t/m^3 ±0.03 (Luxembourg)

Optimum water content

- 42% by weight (Germany)
- 33% by weight (Thailand)
- 52% by weight (Luxembourg)

5.2.2 Shear strength test

The effect of increasing normal forces on MBT samples was tested by the direct shear strength method. Figure 5.11 shows the shear strength curves of MBT material from each country. The shear strength of three different samples did vary with the content of organic in each sample. As the normal force increases, the shear strength of MBT material also increased. It is observed that the shear strength seems to increase with a higher amount of light weight plastics (Thailand no plastics, Germany 2%, Luxembourg 3%).

Angel of internal frictions

- 31.87°±0.37 (Thailand)
- 36.45°±0.7 (Luxembourg)
- 38.63°±0.83 (Germany)

Cohesion

- 5.4 kN/m^2±0.2 (Thailand)
- 12.8 kN/m^2±1.36 (Luxembourg)
- 9.0 kN/m^2±0.22 (Germany)

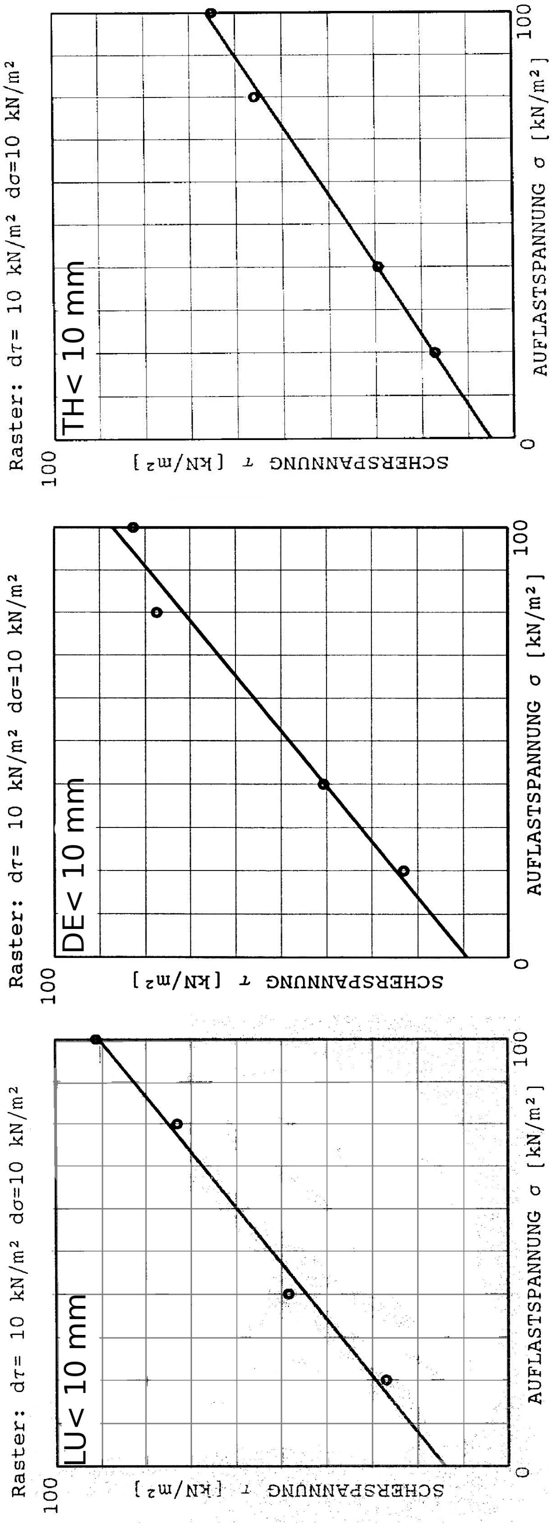

Figure 5.11: Direct shear strength on MBT sample < 10 mm

5.2.3 Permeability test

Figure 5.12 is a graph which was drawn to show the comparison of permeability values of each sample. The permeability values increase with a higher percentage of plastics and fibrous material which were embedded in the fine fraction. The lowest permeability was found in the sample from Thailand (average 8.04 x 10^{-9} m/s, no plastics). Secondly in the sample from Germany (average 1.95 x 10^{-8} m/s, 2% plastics) and the highest value was found in the sample from Luxembourg (average 7.71 x 10^{-7} m/s, 3% plastics). Normally, a high percentage of plastic sheets should lead to a lower permeability [Xie, 2003]. The results shown above are contrary and demonstrate that the amount of plastic in the fraction less than 10 mm is too small to have an effect on permeability. The main reason for a decrease in permeability is the grain size of the sample as shown in Figure 5.12 (Thailand < Germany < Luxembourg).

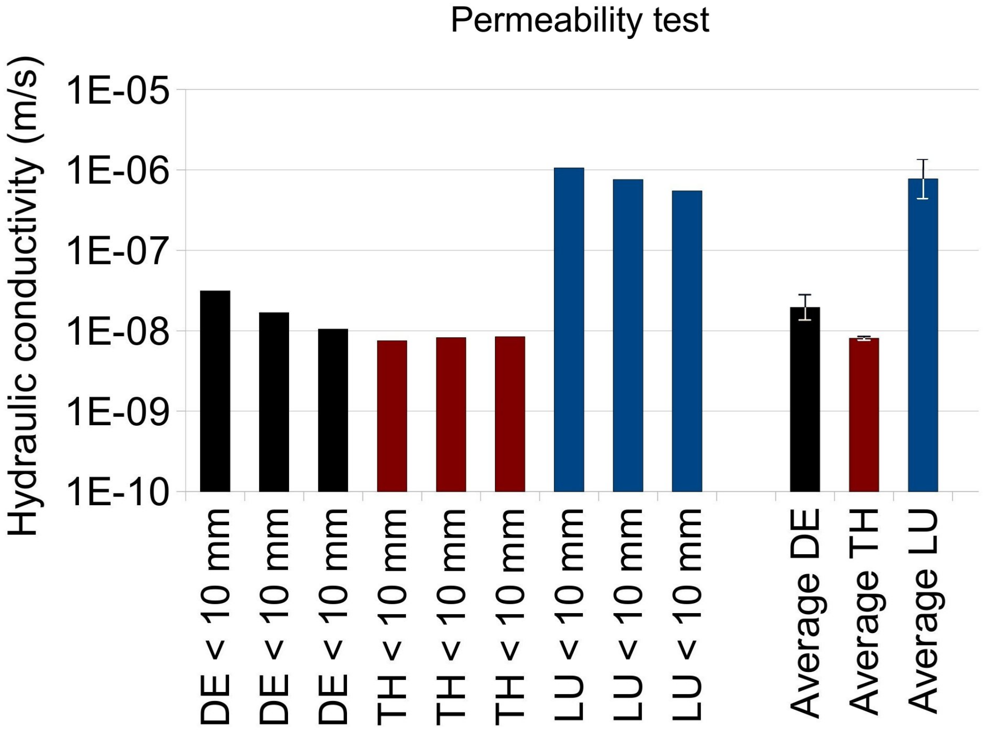

Figure 5.12: Permeability on MBT materials < 10 mm

5.3 Porosity test

Figure 5.13 shows the comparative value of average porosity for different size fractions of MBT material. Porosity in percentage increased with decreasing size fractions. The order of increasing porosity in small size fraction from three study areas is Thailand > Germany > Luxembourg for all size fractions. Table 5.9 presents results of maximum and minimum values for void ratio and percentage of porosity. The maximum porosity is highest in the sample from Thailand (average 43%). Secondly, in the sample from Germany (average 42%) and lowest in the sample from Luxembourg (38%).

In comparison to the porosity of silty sand and gravel in the Table 5.10, the MBT material with a diameter of < 10 mm shows a similar trend. The results of void ratio calculation can be seen in details in the appendix B7 and Table B26.

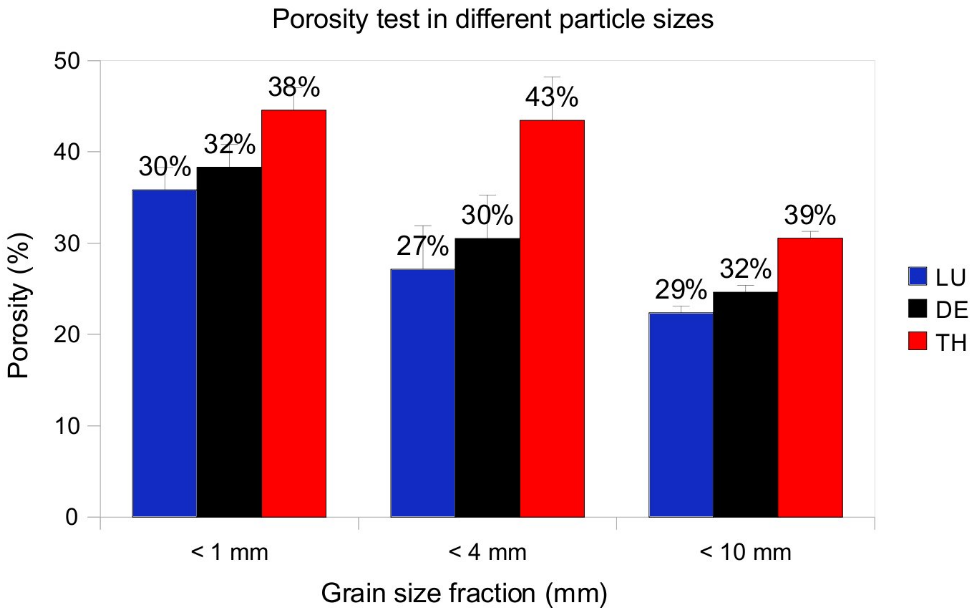

Figure 5.13: Porosity on MBT materials < 10 mm

Table 5.9: Void ratio and porosity of MBT materials < 10 mm

Parameter	Unit	Luxembourg		Germany		Thailand	
		Max.	Min.	Max.	Min.	Max.	Min.
Void ratio	-	0.62	0.27	0.74	0.26	0.87	0.42
Porosity	%	38	21	42	21	43	29

Table 5.10: Void ratio and porosity of silty sand, gravel [Hough, 1957], and MBT waste

Parameter	Unit	Silty sand		Gravel		MBT waste	
		Max.	Min.	Max.	Min.	Max.	Min.
Void ratio	-	0.90	0.30	0.85	0.14	0.87	0.26
Porosity	%	47	23	46	12	43	21

5.4 Water retention capacity test

The water retention capacity was very slow and increased gradually (see Figure 5.14 to 5.16) and the maximum adsorption was not attained after 24 hours. However, the value for water retention capacity of material is taken after 24 hours and corrected with the amount of water evaporated in the porous system of MBT material during the test hours. Results of maximum water retention capacity after 24 hours are shown in Figure 5.17. The percentage of water retention capacity increases gradually with decreasing grain size fraction. Based on these results, we can concluded that the water retention capacity of the MBT samples is high compared to fine sand material (< 30 % after 4 minutes) [Neff, 1988]. The maximum percentage of water retention capacity was found in grain size fraction < 0.25 mm (average 80%) in the samples from Luxembourg and Germany. Average 73% was found in the sample from Thailand and the water uptake was very slow (Figure 5.16). This may be explained by the very low permeability of Thai MBT material.

The water retention capacity curves of 3 fractions of MBT sample from Luxembourg (Figure 5.14) are similar in the fractions of 0.315 – 0.4 mm and 0.25 – 0.315 mm. There is a quicker increasing trend in water adsorption in the fraction of < 0.25 mm.

The water retention capacity of 3 fractions of MBT sample from Germany (Figure 5.15) are reasonably similar. There is a quick uptake of water in the first minutes and hours compared with the Thai sample's curve (Figure 5.16), which shows a slower increasing trend in water adsorption of particles. The type of composition in sample may effect the water retention capacity, especially mineral content. In addition, material structure affects the rate of water movement.

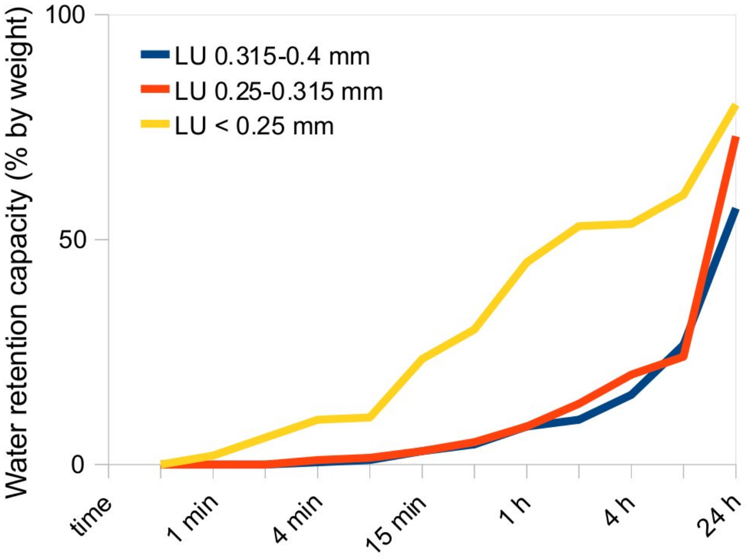

Figure 5.14: Water retention capacity curves of powder samples from Luxembourg

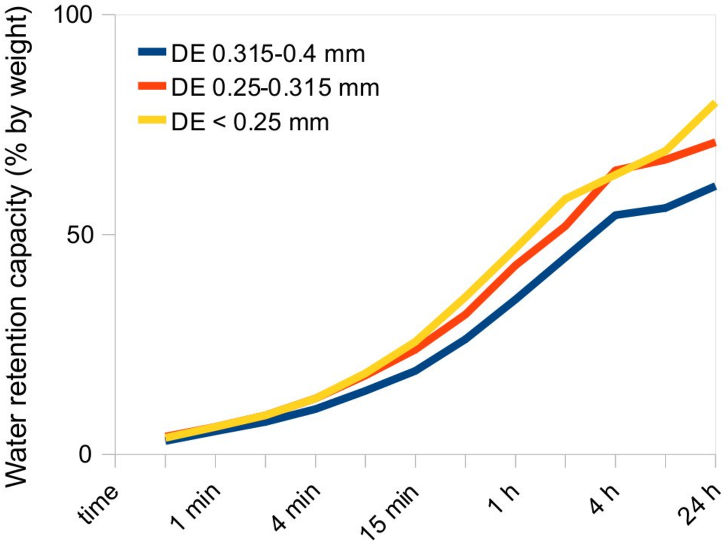

Figure 5.15: Water retention capacity curves of powder samples from Germany

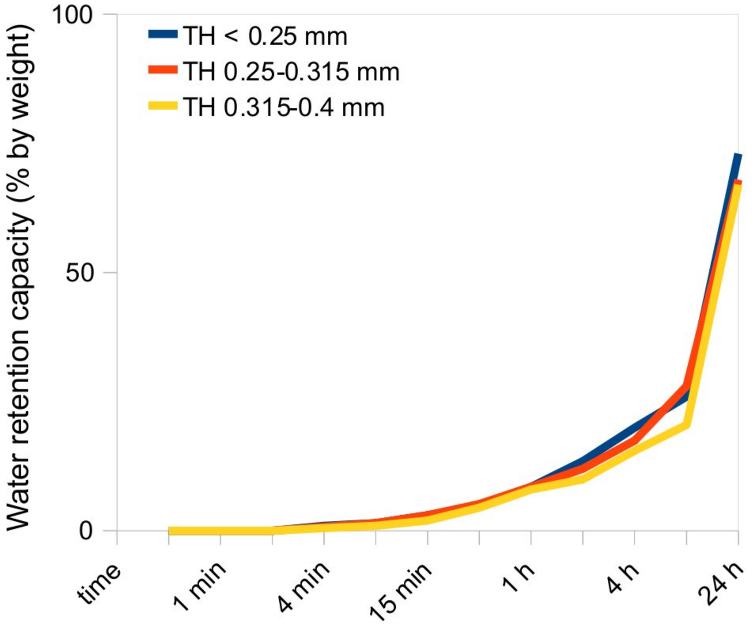

Figure 5.16: Water retention capacity curves of powder samples from Thailand

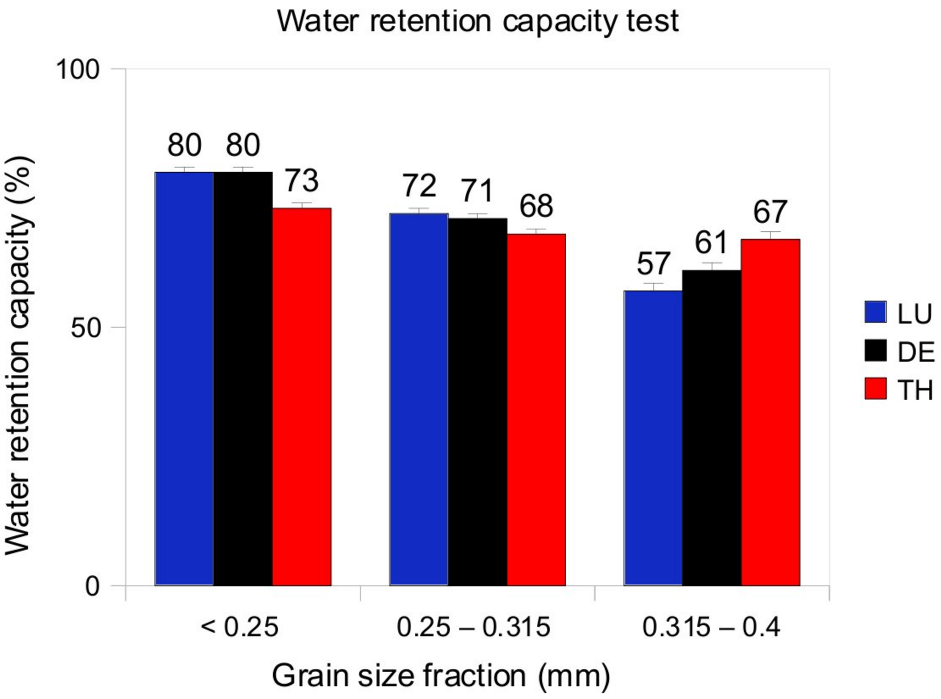

Figure 5.17: Water retention capacity on MBT materials after 24 hours

5.5 Particle shape

MBT material is defined by analysis of physical parameters as a high water absorbing and very low permeable material. Most important properties are the content of organic matter and the small particle size but also material texture and structure have an important effect on permeability and water adsorption. Material structure of MBT waste affects the rate of water movement, available water capacity and retention of water in the landfill body.

The scanning electron microscope creates images of the MBT particles and the chemical characterization of material can be analyzed by Energy-dispersive X-ray Spectroscopy (EDX). The images of MBT material show the shape of MBT particles. Aggregate and smooth surface areas were often found on the MBT materials.

Figure 5.18 shows some analytical results of the microstructures of MBT material < 10 mm from each country by the scanning electron microscope (SEM).

The images of a1 – a3 are samples from Singhofen, Germany; a1 is the image at a scale of 100 micrometers. MBT material are mixed components of needle and round grains in shapes. Those needle grains were found to be natural fiber substances. The pores are the dark areas; a2 is the image at a scale of 10 micrometers. The image shows interconnection between a smooth grain and two aggregated grains; a3 is the image at a scale of 10 micrometers. The image shows crushed grains which covered with aggregated surfaces. The pores are the dark areas surrounded by approximately seven grains.

The images of b1 – b3 are from the sample from Fridhaff, Luxembourg; b1 is the image at a scale of 100 micrometers. Needle grains were found less in the sample. The pores are the dark regions surrounded by more than 100 grains; b2 is the images at a scale of 10 micrometers. The image shows a smooth area of grain which half covered with aggregated particles; b3 is the images at a scale of 10 micrometers. The image shows aggregated areas on a cube grain in shape.

The images of c1 – c3 are sample from Phitsanulok, Thailand; c1 is the image at a scale of 100 micrometers. The image shows a mixture of round, cube and needle grains; c2 shows the image at a scale of 10 micrometers. Aggregated areas were found on a needle grain in shape; c3 is the image at a scale of 10 micrometers. The image shows round aggregated surface on a grain.

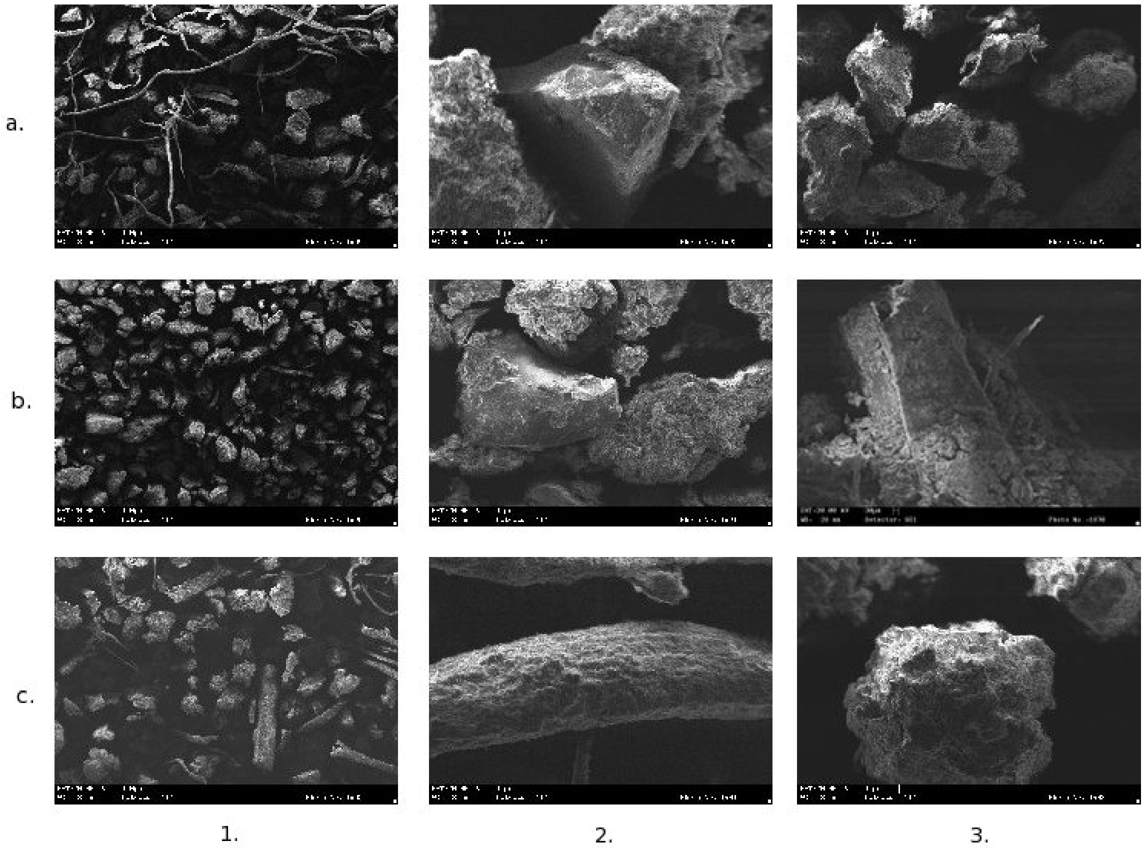

Figure 5.18: Particle shape of MBT materials < 10 mm (SEM photos by Oscar Baeza-Urrea): a1) SEM photo at a scale of 100 micrometers of sample from Singhofen; b1) SEM photo at a scale of 100 micrometers of sample from Fridhaff; c1) SEM photo at a scale of 100 micrometers of sample from Phitsanulok; a2 – a3) SEM photos at a scale of 10 micrometers of samples from Singhofen; b2 – b3) SEM photos at a scale of 10 micrometers of samples from Fridhaff; c2 – c3) SEM photos at a scale of 10 micrometers of samples from Phitsanulok

5.6 Mineralogy

Chemical characterization of the MBT samples had been analyzed by SEM-EDX. The results show metals and non-metals which were found in the smaller part of samples, not all elements can be detected through the EDX. For all possible elements detection, gas chromatography may be better than the technique of SEM-EDX.

Figure 5.19 presents the result of SEM photo at a scale of 100 μm of the sample from Singhofen. The EDX graph which is shown on the right side had been analyzed inside the white circle. The result shows large amounts of O, S, Ca and Si. The result shows also other elements Al, Mg and Fe.

Figure 5.20 presents the result of SEM photo at a scale of 10 μm of the sample from Singhofen. The EDX graph which is shown on the right side had been analyzed inside the white circle. The result shows large amounts of Si and O. The result shows also other elements Na, Al, K and Ca.

Figure 5.21 presents the result of SEM photo at a scale of 10 μm of the sample from Singhofen. The EDX graph which is shown on the right side had been analyzed inside the white circle. The result shows large amounts of O, Si, S and Ca. The other elements are C, Mg, K, Al and Fe.

We may conclude that the elements characterize the following possible compounds for the sample from Singhofen.

- $Si + O$ = Quartz
- $Si + Al + O\ (+K)$ = (Potassium) Feldspar
- $Ca + O\ (+C) = CaCO_3$ = Calcite
- $Ca + S = CaSO_4$ = Gypsum

In Figure 5.19 we have mainly a Gypsum grain with some impurities of a Al-silicate. In Figure 5.20 we probably see a Quartz grain. In Figure 5.21 we can possibly see a mineral particle of Feldspar and Gypsum.

Figure 5.22 presents the result of SEM photo at a scale of 100 μm of the sample from Fridhaff. The EDX graph which is shown on the right side had been analyzed inside the white circle. The result shows large amounts of S, O, Si, Ca, Cl. The other elements are Na, Al, C and K.

Figure 5.23 presents the result of SEM photo at a scale of 10 μm of the sample from Fridhaff. The EDX graph which is shown on the right side had been analyzed inside the white circle . The result shows large amounts of O, Si, Al, Ca. The other elements are Mg and K.

Figure 5.24 presents the result of SEM photo at a scale of 10 μm of the sample from Fridhaff. The EDX graph which is shown on the right side had been analyzed inside the white circle. The result shows large amounts of Si, O, Al, Ca. The other elements are C, Mg, K and Fe.

We may conclude that the elements characterize the following possible compounds for the sample from Fridhaff.

- Si + O = Quartz
- Si + Al +O (+K) = (Potassium) Feldspar
- $Ca + O\ (+C) = CaCO_3$ = Calcite
- $Ca + S = CaSO_4$ = Gypsum
- $(Ca,\ Mg,\ Fe)_2 + (CO)_3)_2$ = Ankerite
- $(Ca\ ,\ Mg)CO_3$ = Dolomite
- $Fe + C + O = FeCO_3$ = Siderit
- $Na\ (+K)\ (+Ca) + Cl$ = Salt

In Figure 5.22 we have mainly a Gypsum grain with some impurities of a Al-silicate and a chloride salt. In Figure 5.23 we probably see a Feldspar and Calcite. In Figure 5.24 we can possibly see a mineral particle of Calcite with Al-silicate.

Figure 5.25 presents the result of SEM photo at a scale of 100 μm of the sample from Phitsanulok. The EDX graph which is shown on the right side had been analyzed inside the white circle. The result shows large amounts of C and O. The other elements are Na, Al, Si, Al, K, Ca and Fe.

Figure 5.26 presents the result of SEM photo at a scale of 10 μm of sample from Phitsanulok. The EDX graph which is shown on the right side had been analyzed inside the white circle. The result shows large amounts of O, Si, Al, Cl and Ca. The other elements are Na, K and Fe.

Figure 5.27 presents the result of SEM photo at a scale of 10 μm of sample from Phitsanulok. The EDX graph which is shown on the right side had been analyzed inside the white circle. The result shows large amounts of Ca, Si, Fe, Al, O and K.

We may conclude that the elements characterize the following possible compounds for the sample from Phitsanulok.

- $Si + O =$ Quartz
- $Si + Al + O$ $(+K) =$ (Potassium) Feldspar
- $Ca + O$ $(+C) = CaCO_3 =$ Calcite
- $C + O =$ Organics
- $Fe + O = FeO =$ Iron oxide

Figure 5.25 we have mainly organic particles with some impurities. In Figure 5.26 we probably see Calcite with Al-silicate. In Figure 5.27 we can possibly see Feldspar, Calcite and a possible iron oxide.

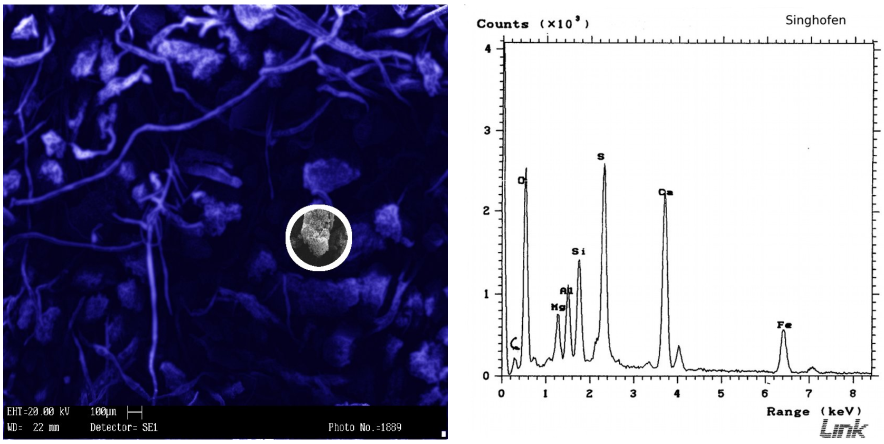

Figure 5.19: EDX analysis of MBT sample from Singhofen (by Oscar Baeza-Urrea)

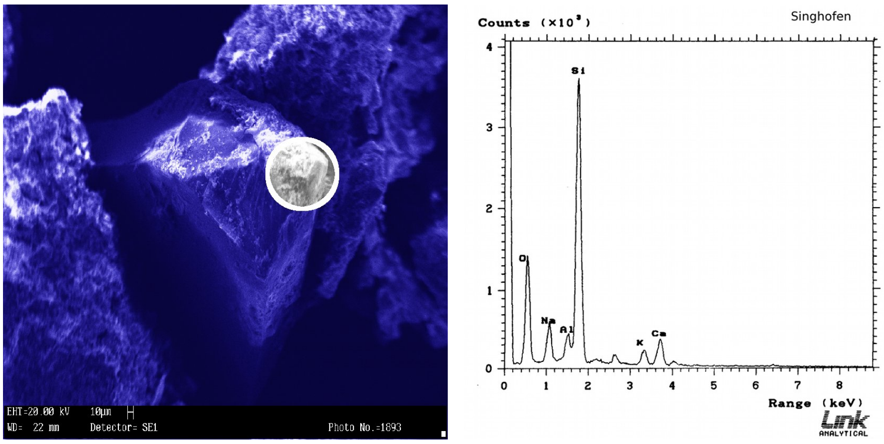

Figure 5.20: EDX analysis of MBT sample from Singhofen (by Oscar Baeza-Urrea)

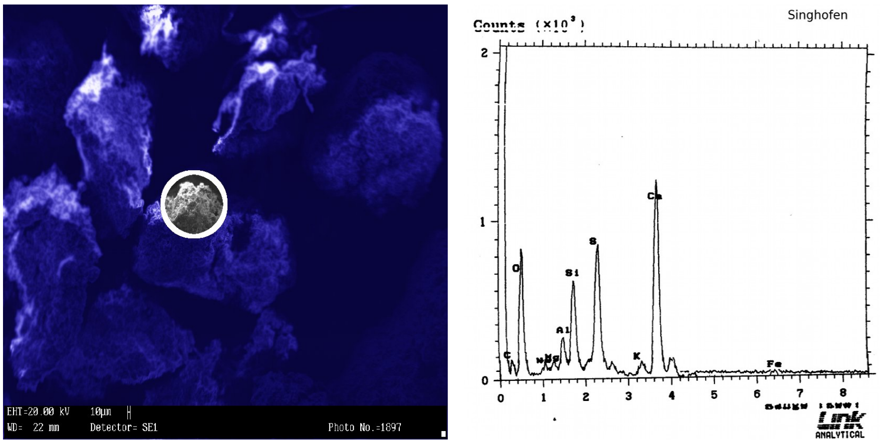

Figure 5.21: EDX analysis of MBT sample from Singhofen (by Oscar Baeza-Urrea)

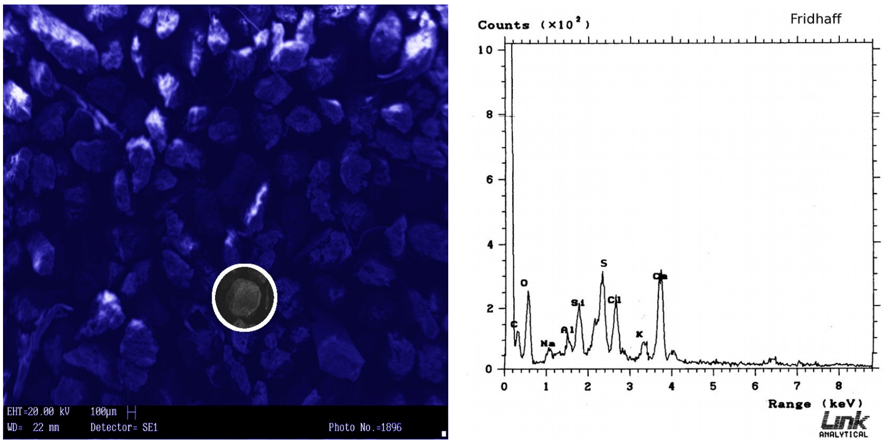

Figure 5.22: EDX analysis of MBT sample from Fridhaff (by Oscar Baeza-Urrea)

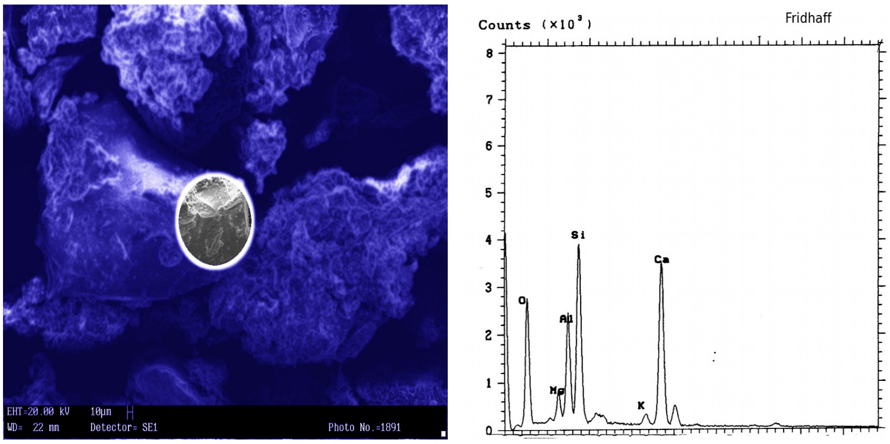

Figure 5.23: EDX analysis of MBT sample from Fridhaff (by Oscar Baeza-Urrea)

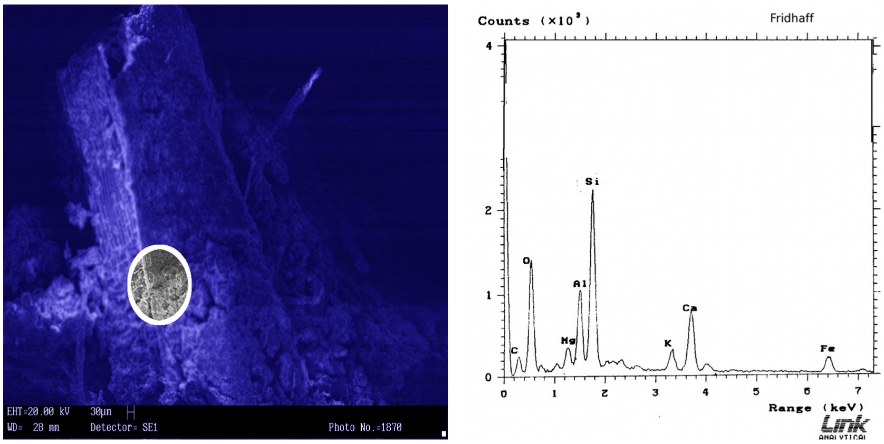

Figure 5.24: EDX analysis of MBT sample from Fridhaff (by Oscar Baeza-Urrea)

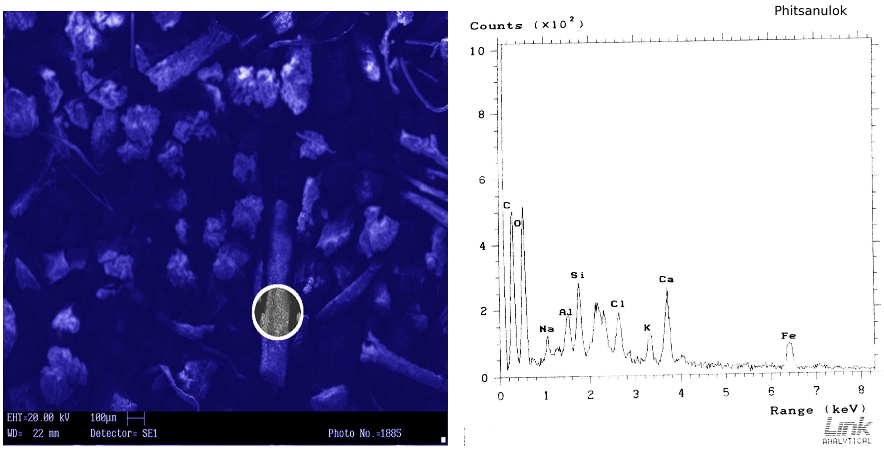

Figure 5.25: EDX analysis of MBT sample from Phitsanulok (by Oscar Baeza-Urrea)

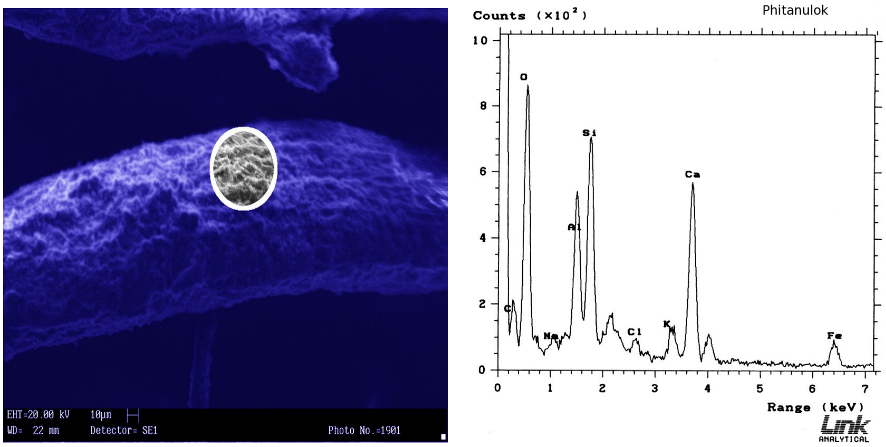

Figure 5.26: EDX analysis of MBT sample from Phitsanulok (by Oscar Baeza-Urrea)

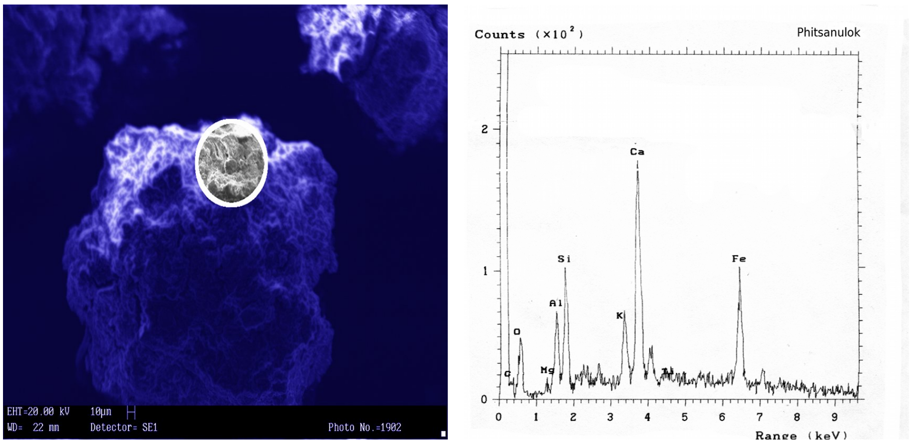

Figure 5.27: EDX analysis of MBT sample from Phitsanulok (by Oscar Baeza-Urrea)

5.7 Chemical analysis of the extracted eluate

Figure 5.28 shows the samples of extracted eluate of MBT materials. They were visibly characterized as brown color, viscous fluid with particulates. They were analyzed for the chemical composition of leachate: chemical oxygen demand (COD), ammonium (NH_4^+), sulfate (SO_4^{2-}), chloride (Cl^-), lead (Pb), cadmium (Cd) and arsenic (As).

Based on the results in Figure 5.29, highest COD concentrations were found in the sample from Luxembourg (average 3,631 mg/L). The second highest was found in the sample from Thailand (average 2,783 mg/L). The lowest was in the sample from Germany (average 2,158 mg/L).

For NH_4^+ concentrations, the highest value was found in the sample from Thailand (average 29 mg/L). Secondly, in the sample from Germany (average 21 mg/L). The lowest value was in the sample from Luxembourg (average 20 mg/L).

Results of SO_4^{2-} concentrations show the decreasing average values in the order Thailand $>$ Germany $>$ Luxembourg. The values were 1,633, 1,042 and 867 mg/L, respectively.

In contrast, the highest Cl^- concentration was found in the sample from Germany (average 675 mg/L). Second highest was found in the sample from Luxembourg (average 617 mg/L). The lowest was in the sample from Thailand (average 608 mg/L).

Figure 5.30 shows the concentrations of heavy metals in the extracted eluate from the study areas. Results show that Pb was mostly found in eluate of MBT samples, while As was not detected in the eluate samples of all countries. The highest concentration of Pb was found to be 0.295 mg/L in the sample from Germany. Secondly was found to be 0.252 mg/L in the samples from Luxembourg. The lowest was found to be 0.220 mg/L in the sample from Thailand. Cd concentrations were similar in all samples. All heavy metals were found much lower than the allocate criteria of Germany: (Pb) $\leq$ 1 mg/L, (Cd) $\leq$ 0.1 mg/L and (As) $\leq$ 0.5 mg/L) (see Table 5.11).

In general, heavy metals are found both onside and inside the particle of waste, when pH is low, heavy metals move and combine with the organic substances. Metal solubility is higher at low pH during acid formation phase restricted by ligands both organic and inorganic. The solubility drops during fermentative phase due to rise in pH. The differences of eluate characteristics between Luxembourg, Germany and Thailand can not be explained in detail.

A comparison of eluate characteristics (pH, COD, NH_4^+, SO_4^{2-} and Cl^-, Pb, Cd, As) of the MBT samples from this study with the German limit values for MBT waste and untreated waste is shown in Table 5.11. Eluate quality of the MBT samples in this study comply with the German Eluate limit values for MBT waste. The pH value of MBT samples was found to be 8 in average. It is in the range of the German limit values. The eluates of MBT samples were found to show a very low amount of pollution. Comparison with the data of [Dachroth, 1992] on polluted leachate of untreated waste was found that COD concentration of MBT samples is extremely reduced. Ammonium, sulfate, chloride were not much reduced. Comparison with the data of Fellner, 2008 was found that COD and SO_4^{2-} concentrations of the MBT samples are in the range but the concentration of chloride is lower. A higher reduction of pollution in eluate is found in older stabilized waste and longer rotting period of waste.

Figure 5.28: The extracted eluate in volumetric flasks by the standard procedure (1:10 solid/liquid ration and 24 hours shaking)

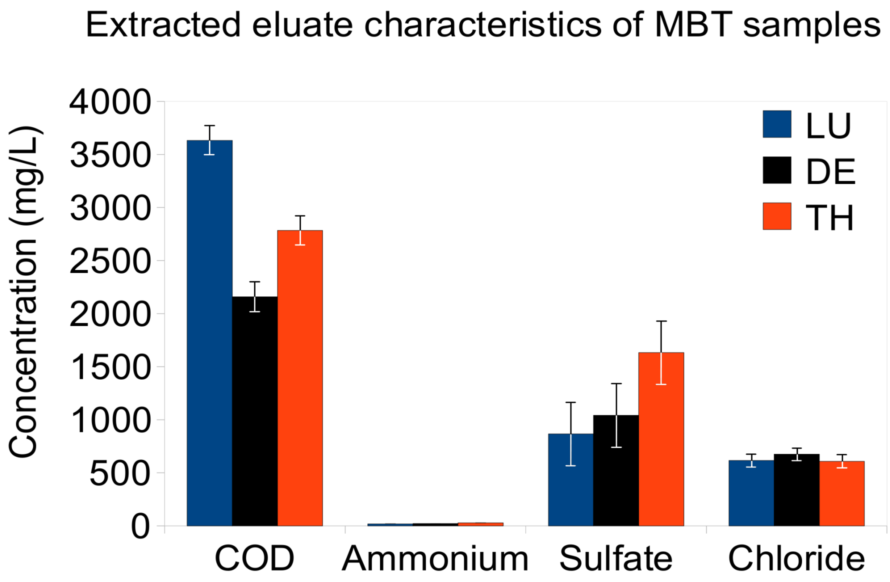

Figure 5.29: Distribution of chemical concentrations in the extracted eluate of MBT material

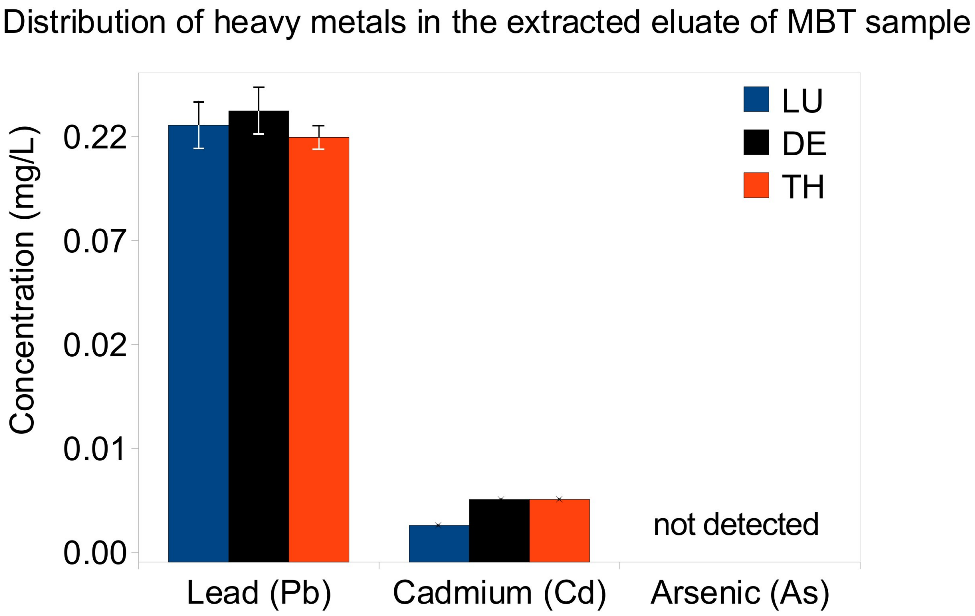

Figure 5.30: Distribution of heavy metals in the extracted eluate of MBT material

Table 5.11: Eluate characteristics of MBT samples and untreated waste and German limit values

Parameters	Unit	Eluate MBT waste Luxembourg	Eluate MBT waste Germany	Eluate MBT waste Thailand	German limit values for MBT waste (Körner, 2006)	Untreated waste (Dachroth, 1992)	Leachate MBT waste (Fellner, 2008)
pH	-	8.28	8.17	8.0	5.5 to 13	3.5 to 9	6.4 to 8.4
COD	mg/L	3,631 ± 137[a]	2,185 ± 219	2,783 ± 147	-	500 to 60,000	400 to 8,300
NH_4^+	mg/L	19 ± 2	21 ± 1	29 ± 5	≤ 200	20 to 3,000	< 0.1 to 1,000
SO_4^{2-}	mg/L	866 ± 297	1,041 ± 266	1,633 ± 185	-	50 to 3,000	50 to 10,500
$Cl-$	mg/L	616 ± 58	657 ± 81	608 ± 31	-	100 to 15,000	800 to 16,000
Pb	mg/L	0.25 ± 0.1	0.29 ± 0.1	0.22 ± 0	≤ 1	0.02 to 1	< 0.005 to 1.6
Cd	mg/L	0.003 ± 0	0.004 ± 0	0.004 ± 0	≤ 0.1	-	-
As	mg/L	ND	ND	ND	≤ 0.5	-	-

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[a] All values are given as the mean ± standard deviation, ND, not detected

Chapter 6

Discussion

6.1 Sites characteristics

Variances of MBT operations

MBT technology focus on the principal to decompose the organic waste components under aerobic conditions before the waste is finally dumped to landfill sites. However, technologies are different in each location in terms of technology requirements, costs and effects on the environment.

Each country in the study has different MBT processes see chapter 4. The important variances of MBT operations in the three countries can be summarized in Table 6.1.

Table 6.1: Summarized important variances of MBT techniques

Parameters	Luxembourg	Germany	Thailand
Start-up	Year 2006	Year 2000	Year 2001
Method	medium	medium	simplest
Cost	high	high	low
Size of sieve	150 mm	80 mm	no sieving
Composting	single stage	two stages	single stage
Duration of rotting period	6 weeks	15 weeks	9 months
Waste reduction (by weight)	50%	65%	64%

The reasons why countries pretreat their waste differently depend on the main reasons of cultures, economic situation, experience and political systems. These factors affect the characteristics and properties of the finished MBT material as well as the potential of waste reduction in landfills.

- Method

  The method is described in term of using different instruments in mechanical sorting and screening of the waste such as cutting machines, magnetic separators and size screening machines. The technology is high in industrialized countries. In addition, having facilities is mostly related to experience, funds and objectives in enhancement of waste recovery in each country.

- Cost

  The complex method of treatment is related with high costs for the operation. The Linkenbach MBT plant invested approximately 36 million euro in the facility. The annual MSW capacity is around 90,000 tons. Germany and Luxembourg have to consider on the running costs for the emission treatment such as leachate and exhaust air collection systems, wages of the workers and maintenance costs. Those are higher costs of treatment than the simple aeration composting in Phitsanulok.

- Size of sieve

  The size of trommel sieve is a factor of an efficient sorting technique. The trommel sieve of Luxembourg (150 mm in diameter) is larger than the trommel sieve using in Germany (80 mm in diameter). The reasons for using bigger size sieves are easier cleaning and the cost reduction. However, it is obvious that the small size of trommel sieve recovers more smaller particle size. As the result of size fraction, large size > 40 mm was most found in sample from Phitsanulok where does not use a trommel sieve at the mechanical treatment.

- Composting, duration and waste reduction

  The type of composting is a factor of efficient degradation. An aeration system for composting is accepted to be the most efficient biological treatment. The three countries have different styles of aeration composting system. Luxembourg fills material in the tunnels-series with leachate recirculation as a single intensive composting system (only 6 weeks). While, Germany treats their waste biologically in a closed installation which is connected to the aeration for initial composting stage. The waste is homogenized with leachate before sending to the composting hall. The second composting stage is done at an open installation with an aeration system. Total composting period is about 15 weeks. For Thailand, simple aerobic composting in shape of trapezoidal windrow, palettes and ventilation pipes are utilized under natural condition. Windrows are covered with coconut husks as bio-filter. The composting period is 9 months.

  The duration of the rotting period is a factor of stabilized material. Material is not constant and stable in a short period of rotting period. As Luxembourg gives only 6 weeks of aeration rotting period without a period of drying, the finished material is found to be not enough stabilized material. Pollutant as COD concentration remained high in the eluate sample from Luxembourg (Figure 5.29). The total duration of rotting period of MBT from Germany is 15 weeks. Based on the result of eluate quality. The two stages of composting types brings more stabilized material.

  The waste reduction is an important index which reflects the effective MBT system. Waste reduction is described in term of percentage of total waste reduction. The calculation by weight was done by the measurements of initial weight of MSW arriving to the mechanical treatment and the final weight of MBT material before sending it to landfills. Based on the result of waste reduction, the highest waste reduction was found to be in MBT system from Germany with total waste reduction of 65% by weight [Linkenbach, 2005]. Secondly was found in composting type from Thailand (64% by weight) [Tungtakanpoung, 2006]. The lowest waste reduction was found in composting type from Luxembourg (50% by weight) [SIDEC, 2006].

  Effective waste reduction associated with content of biodegradable waste, sorting technique, composting type, and duration of rotting period. As the organic waste composition between Luxembourg and Germany is not significant different but the efficient waste reduction in Germany [Linkenbach, 2005] is higher. Since the size of trommel sieve is smaller and the rotting period takes longer. Although Thailand does not use trommel sieves, the percentage of waste reduction [Tungtakanpoung, 2006] is as high as in Germany. The reasons are the higher component of organic waste and an appropriate designed windrows. The waste is decomposed rapidly due to continuous supply of oxygen for the biological decomposition activity is available.

6.2 Particle size distribution

The particle size distribution curves of MBT samples from the three countries are obviously different as shown in Figure 6.1. The result of particle size distribution show that MBT material can be classified as coarse sand to coarse gravel. Highest fine fractions (< 10 mm) could be found for MBT material from Germany.

Efficiency in removing large sizes of high calorific fractions and recyclable materials is related to particle size distribution. In particular, helping facilities such as trommel sieve and magnetic separator play a great role in particle size reduction. Germany has used the trommel sieve with a size of hole (80 mm in diameter). Luxembourg has used the larger size of hole (150 mm in diameter). The smaller size of sieve can better screen fine particles out of coarser particles. Thailand does not use trommel sieve, the size of waste input is reduced only by sprockets inside a mobile rotary drum to open the closed plastic bags, thus coarser particles remained higher than the other two. This may be one explanation of why MBT material from Germany has more fine particles.

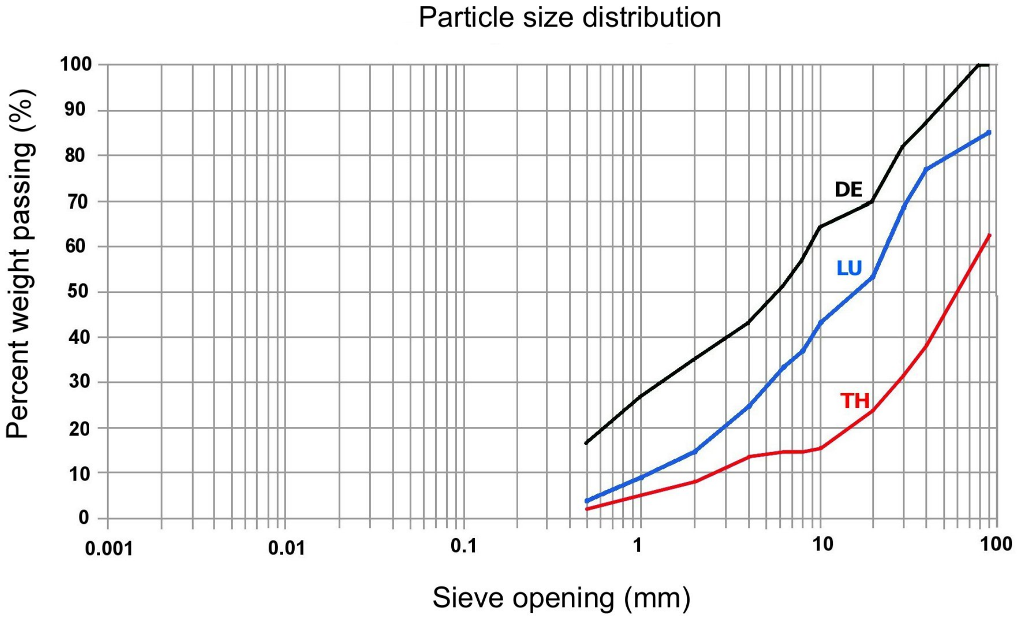

Figure 6.1: Comparative particle size distribution curves of MBT materials

The size distribution curves of fine particles < 10 mm in diameter (Figure 6.2) show the opposite trend. These small particles are visibly similar to soil materials. Particles are typically not uniform. A trend of highest fine particles was found in the sample from Thailand.

Although, Thailand does not use trommel sieve to screen and reduce particle size, high organic composition mainly food waste is more easily to be degraded and decomposed. The method of composting windrow which is covered with coconut husks under natural conditions improves the biodegradation. This is because the optimum water and air associates with waste.

Highest coarse particles was found in the sample from Luxembourg. The predominant coarse materials in sample was found to be very thin plastic fragments and packing materials, small pieces of glass, ceramic and sponge. It is possible that cutting machine breaks often large material into small pieces and these material pass through the large size of trommel sieve's hole, thus they were easily embedded into biodegradable fraction. This happens also in case of Germany. However, the percentage of coarse particles in small size sample is less due to using smaller size of trommel sieve's hole. The short period of biological treatment effects particle size distribution. This is because of the increase of fine fraction continues with the extended period of composting.

The distribution of fine particles in MBT sample from Luxembourg is less due to the large size of trommel sieve's hole and the short period of aeration composting system.

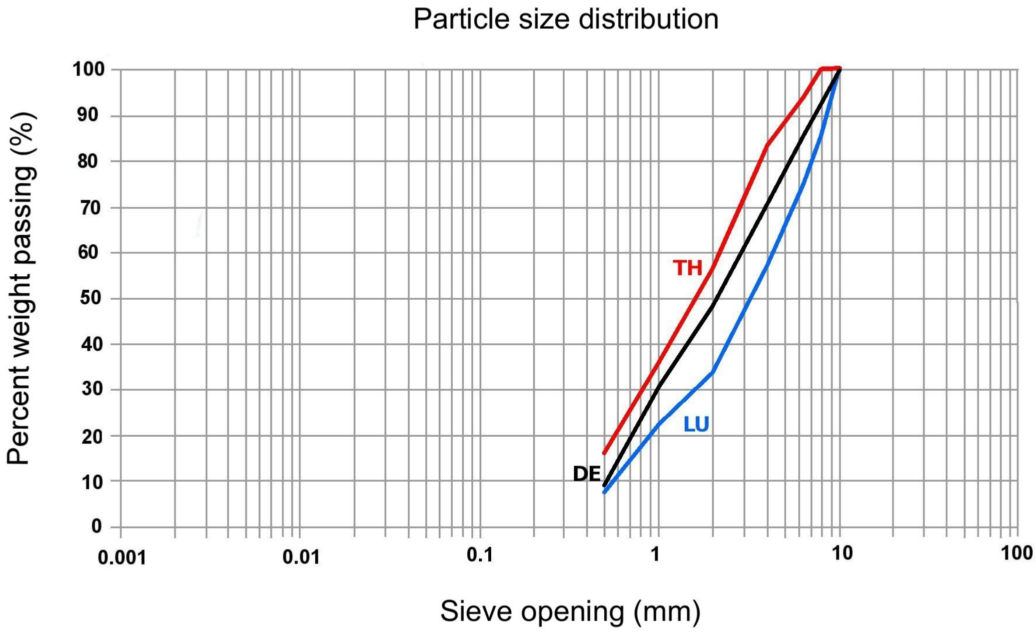

Figure 6.2: Comparative particle size distribution curves of MBT material (<10 mm)

6.3 Relationships of particle size and geotechnical properties

The size distribution of MBT material plays a critical role in geotechnical properties. From particle size analysis, particles coarser than 10 mm exhibits high content of fibrous components. From both a hydraulic and geotechnical point of view, these particles are of limited importance in water movement and holding capacity. In order to evaluate the potential application of the small size material as a final cover of landfill, it is essential to have information on the geotechnical parameters from different sources. In geotechnical study, particles coarser than 10 mm were discarded, the small size < 10 mm of MBT samples were possibly tested in the laboratory of conventional soil mechanics.

The content of compost was found highly in MBT samples < 10 mm in diameter from Thailand. The same size of samples from Luxembourg and Germany contain more other multiple substances such as plastic fragments, small pieces of glass and ceramics and were not completely composed of compost. The content of compost in MBT material may continue to increase as the particle sizes decrease and also increase with respect to period of biological treatment.

Proctor density

From the results, the proctor densities of the MBT samples from the study areas were found in the range of 0.78 to 1.04 t/m^3. The range of optimum water content was 33 to 52%. The values of density varied with content of compost particles.

In comparison with the proctor densities for aeration rotting composting of the MBT material < 25 mm in diameter from another laboratory, the Proctor density values were in the range of 0.70 to 1.20 t/m^3 of dry matter with the high optimum water content between 28 to 40% [Bauer et al., 2006]. Barone [2008] found that the maximum compacted density of MBT waste is between 0.7 to 1.0 t/m^3 with optimum water content of 25 to 33%. The results from this study were close to these earlier reported results.

Some studies found that the material from anaerobic treatment had smaller proctor densities with higher values of optimum water content. Proctor curves of MBT materials often show a pre-dominantly flat gradient therefore the range of optimum water content is relatively high [Bauer et al., 2006]. MBT material after compaction in landfill can reach the density of 1.2 to 1.6 t/m^3, compared with the density of untreated waste (0.4 t/m^3) Fellner [2009]. In this regard, smaller particles are of more concern than larger particles because they have a relatively high surface areas that facilitates the water saturation of disposal material.

Shear strength

From the results, the average shearing angles of MBT samples from the study areas were found in the range of 31°to 38°. The average cohesion were in the range of 5 to 13 kN/m^2. Fellner [2009] reported that the shearing angle of fresh waste was 40°with a cohesion of 50 kN/m^2. The shearing angle decreases with increasing finer particles. Thus, the shear strength of MBT material is smaller than the untreated waste.

Bauer et al., [2007] noted that MBT material with sizes of 40 to 60 mm contained high amount of fibrous components and it made the determination of conventional shearing angle and cohesion difficult. A problem concerning the landfill stability for MBT landfill. The shearing angle was found to be 38°with cohesion of 35 kN/m^2. With the decreasing shearing angle of MBT material, the stability problem on landfill may occur. Bauer et al. [2006] suggested that the slope gradients of untreated waste landfills at an angle larger than 1:1, slope angle $>$ 45°are stable over years. For the MBT material this means that the embankment slope needs to be flattened. A sufficient long term stability for the embankment slope gradients of MBT material is calculated about 1:3.

The strength value of soil material increases due to grading, packing density and grain angularity [Farrar, 2004]. In the same way, the shear strength of MBT material is higher after compaction [Müller and Fricker 1993; Leikam and Stegmann 1998; Bauer et al. 2007]. Therefore the stability problem may be improved.

Permeability and Porosity

The very low permeability was found to be associated with small particle size, content of organic substances, plastic fragments embedded in the material and/or the degree of compaction [Obermann, 1999 and Xie, 2006]. The flow movement of water through the MBT material is often characterized by saturated hydraulic conductivity with the calculation of the Darcy's law. From the results, the average permeability of MBT samples varied with content of compost and plastic fragments. The permeability ranged from 10^{-7} to 10^{-9} m/s.

Xie et al., [2006] found that the MBT material shows a rather low permeability, although it has relatively coarse particle sizes up to 40 mm. The values of permeability varies between 10^{-7} to 10^{-9} m/s [Bidlingmaier, 1997 and Xie, 2003]. The results of permeability in MBT material from study areas were close to these reported results. Some studies indicated that permeability is reduced with decreasing particle size. Particle size with a diameter of < 25 mm shows permeability less than 10^{-10} m/s and less than 10^{-11} m/s in particle size with a diameter of < 12 mm [Binner, 2002].

From the results of porosity analysis, the MBT material has relatively high porosity compared to the porosity values of gravel and silty sand. Porosity varies continuously with grain size, mineral composition and shape of porous material.

It is known that well sorted grain size of soil has plenty of connectedness of pore space, high porosity and high permeability, allowing the water to drain out of the soil quickly. If the materials are poorly sorted (lots of different sizes) then it reduces porosity because smaller grains fall between larger grains. In general, a positive relationship between porosity and permeability can be seen or the relationship can be negative if the pores are not connected.

Therefore the texture, grain size and sorting of materials play a critical role in both porosity (%) and permeability (k). MBT material was found to be poorly sorted material (see subsection 5.2.1) and this explains that smaller particle size of material decreases porosity.

Water retention capacity

Water retention capacity refers to the amount of water that a porous medium can retain, against gravitational pull, before discharge. From the results, MBT small sizes were found to be high water retention capacity. A trend of increasing water retention capacity was found with decreasing particles. In addition to the water holding in MBT material, the transporting pollutants plays a critical role in disposal waste. Smaller particles have a relatively high surface area. This means that the adsorption of pollutants is higher in smaller particles. With this immobilization of pollutants, leachate contamination reduces.

6.4 Composition and water content

From the results of MBT waste composition analysis, all kind of plastics were often found in particles > 40 mm in diameter of all MBT samples from study areas. Various materials were found in particles 10 – 40 mm in diameter of all samples. Compost was a majority in particles < 10 mm in diameter of all samples. Percentage of compost increases in the order of Luxembourg, Germany and Thailand. Inert (glass and ceramic), textile, and plastic remained much higher in this size of sample from Luxembourg. There was less of those components in this size of sample from Germany. In contrast, there was not found any of those components in this size of sample from Thailand.

Luxembourg and Germany cut and shred more mixed waste input with machine than Thailand. With homogenization activity before biological treatment, small crushed plastic fragments are easily embedded in organic material. In addition, the duration of rotting period effects the transformation of decomposable material. Longer aerobic composting period transforms the easily decomposable and accessible part of the organic waste to all compost material.

The water content is a useful parameter to determine the amount of water in material and to estimate the leachate production in landfill. From the results in this study, the values of water content in all samples increased with decreasing particle sizes. It is obviously that the smaller particles had higher biodegradable components than the larger particles. The water content of MBT samples from study areas ranged from 25 to 39% by weight in average. An increasing water content was found in order of Thailand $<$ Germany $<$ Luxembourg.

The water content of the MBT material after the treatment process is actually reduced from the initial water content. On one hand, Luxembourg and Germany add water (leachate) in material during the homogenization and/or biological treatment. On the other hand, the water content in MBT material after composting process of Germany was relatively less than Luxembourg. This is due to the fact that Germany has a second biological treatment (working with aeration system) which reduces water content in their MBT material prior to sending them to landfill. There is only one stage of intensive biological treatment in Luxembourg. In general the duration of the rotting process decreases the water content of MBT material.

6.5 Total Organic Carbon and pH

Total organic carbon (TOC) is a parameter to determine the reduction of biological activity in organic substances. The limit value of TOC in solid matter of the MBT material is indicated at $< 18\%$ in the dry matter (allocate criteria of German waste storage ordinance). From the results, the small size of sample had higher value than the medium and larger sizes. The smaller size samples contained more compost than the other samples. The mean values of TOC in MBT samples ranged from 7.45 to 11.8%. The TOC value of sample from Phitsanulok, Thailand is lowest, followed in order of increasing TOC values by Singhofen, Germany and Fridhaff, Luxembourg.

A possible explanation for lower content of organic carbon in MBT sample from Thailand could be the longer period of composting treatment and contents of easier biodegradable waste. Other studies indicated that extended pretreatment period will provide a lower value of biological activity [Tränkler and Visvanathan, 2002] and Soyez [2001]. Lichner et al., [2005] reported that the mean total organic carbon in agriculture soil ranged 5 to 15%, the value of MBT material was about 11% which was much lower than the values of the untreated waste (27 to 32%) [Leikam and Stegmann, 1999]. Thus the mean value and range of TOC of the MBT samples from this study is close to the value of these earlier reported results.

The pH is an important index which indicates the basic chemical characteristics of MBT material. Fellner [2009] noted that average pH values of MBT landfill in Austria ranged from 7.5 to 7.9. The MBT samples in study areas were found to be slightly basic. The mean values of pH in MBT samples from the three countries ranged from 8.0 to 8.28. The pH of MBT samples were relatively similar in all sizes, although there was a little higher value of pH in samples from European. More alkaline substances such as battery, electronic particles and industrial particulate material were found in the European samples.

6.6 Eluate composition

Organic load concentrations

Landfill leachate is characterized as a water-based solution of four groups of pollutants (dissolved organic matter, inorganic macro components, heavy metals, and xenobiotic organic compounds). It is a high strength wastewater characterized by high levels of organic constituents and ammonia, potentially containing toxic contaminants such as heavy metals. MBT waste produces less amount of landfill leachate. MBT waste has also a much lower specific pollutants load compared to the untreated waste. The results of leachate quality tests prove that the acidification is reduced by the MBT processes. The mean pH values of MBT samples from the study areas were about 8, while the pH value of untreated waste may be considerably lower (3.5 to 9) [Dachroth, 1992].

Figure 6.3 illustrates the impact of pretreatment on COD concentrations in eluate. Pretreated waste showed a positive effect on COD concentration. The eluate of young untreated waste showed average COD concentration of about 50,000 mg/L [Fellner, 2008]. In comparison to the eluate MBT samples from study areas, the COD concentration (2,158 – 3,631 mg/L) in treated waste is reduced for about 20 times by the pretreatment process. Some studies in Austria reported that the COD concentration in MBT eluate were in range of 200 – 2,300 mg/L [Binner, 2002] and 1,000 – 4,000 mg/L [Fellner, 2009]. Ziehmann et al. [2003] was found to be 414 – 1,064 mg/L in the MBT sample from Germany. The COD concentration of MBT material decreases much more with increasing period of disposal [Visvanathan et al., 2005 and Warnstedt, 2005].

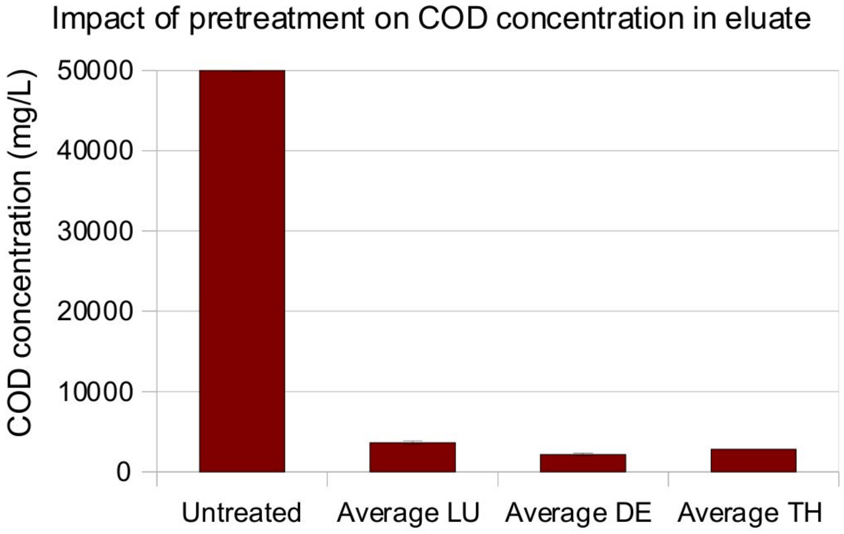

Figure 6.3: Impact of pretreatment on COD concentrations in eluate

Inorganic load concentrations

Figure 6.4 shows the impact of pretreatment on ammonia concentration in eluate. The average ammonia concentration of the untreated waste was about 2,200 mg/L. The ammonium concentrations of MBT material in the study areas ranged from 20 – 29 mg/L. In comparison to the eluate sample of the treated waste, the ammonia concentration is reduced for about 100 times by the pretreatment process. The average values of ammonia concentration in MBT eluate was 10 – 350 mg/L [Fellner, 2009].

Fellner [2009] also noted that the average values of chloride (Cl^-) and sulfate (SO_4^{2-}) in MBT eluate were 4,100 – 11,300 and 700 – 9,500 mg/L, respectively. The results of (Cl^-) and (SO_4^{2-}) from this study were 608 – 675 mg/L and 867 – 1,633 mg/L, respectively. The values of inorganic-salts in MBT eluate from this study were in the lower ranges of earlier reported results.

For the result of heavy metals analysis, the study of Fellner [2009] showed that average values of Pb and Cd in MBT eluate were 0.01 – 0.5 and 0.01 – 0.15 mg/L, respectively. Pb and Cd concentrations in this study were found to be average 0.2 – 0.3 mg/L and 0.003 – 0.004 mg/L, respectively. The solubility of heavy metals is actually low because of high pH value.

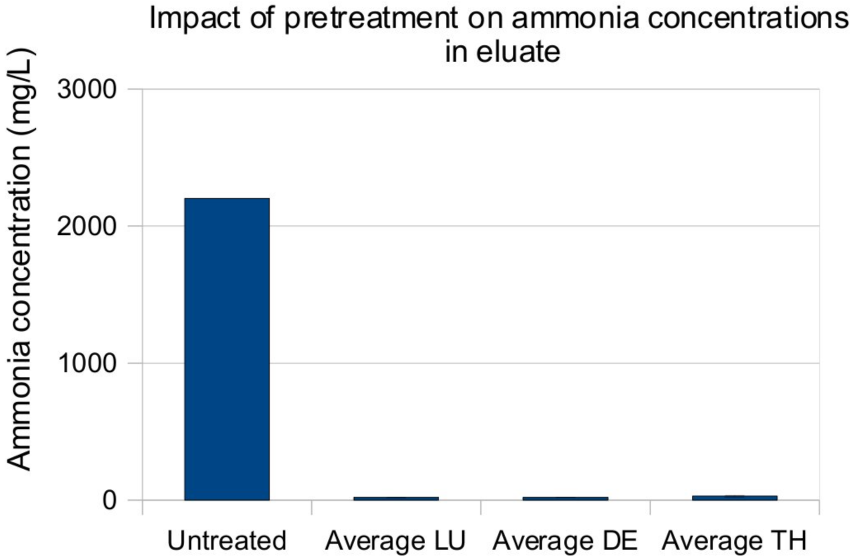

Figure 6.4: Impact of pretreatment on ammonia concentrations in eluate

Chapter 7

Conclusion

Luxembourg, Germany and Thailand are countries with different economic systems, politics and cultures. However, all three countries have the common aim to conduct high level research and development for environmental solutions for their waste problem.

Although the main target of MBT technology is the same in those countries, the method of treatment and implementation differs due to local policy application, funds, experience and culture reasons. Table 7.1 shows the important differences of the pre-treatment in Luxembourg, Germany and Thailand and the impacts of their techniques to their MBT material characteristics. Positive and negative aspects of the management and treatment systems in each country are shown in Table 7.2.

Important conclusions from this comparative study can be drawn as following:

1. The German MSW generation rate has increased steadily from 419 kg/capita in 2003 to 581 kg/capita in 2008 [OECD, 2008]. However, the amount of biodegradable waste that goes into landfills in Germany has declined. Approximately 35% by weight of MBT waste is landfilled at Linkenbach MBT plant. Without their effective waste prevention measures and the increasing of MBT, there would be even a smaller amount of biodegradable waste (percentage of the total amount of waste). Luxembourg showed a quicker increasing waste generation rate from 426 kg/capita to 701 kg/capita over the same period [OECD, 2008]. This is due to the rapid economic and increasing standard of living. At present, Fridhaff MBT plant reduces MSW approximately 50% by weight. The other 50% of MBT waste is landfilled. In Thailand, the rapid economic and changing lifestyles also makes an increasing waste generation. Approximately 90% of total MSW is landfilled. At present, MBT in Thailand is found only in Phitsanulok province. Hopefully, in future, MBT can be promoted everywhere without any patents of any company. Furthermore, Luxembourg and Thailand need to pay attention on better strategies on waste management policies, increasing pretreatment for waste which goes into landfills and promoting recycling behavior and waste minimization.
2. Source separation system is well regulated in European countries, as well as sorting technology for solid waste. MSW recovery and recyclable waste have increased significantly in Germany due to effective sorting technology for mixed household waste in MBT plants. Waste which can be recycled such as paper, glass, and metals is separated out from the total remaining waste for approximately 40 – 50% [Linkenbach, 2005]. Although Fridhaff MBT plant in Luxembourg shows a high level of sorting facilities for mixed household waste, the effectiveness is less than that in Linkenbach and Singhofen MBT plants in Germany. Therefore a good training of the operational staff to do sorting and separation are more important. In Thailand, there are low sorting facilities. Although the organic waste is an high amount part in fresh waste, organic waste is less separated out of the mixed household waste. This is mostly because there is none or less of waste separation by private households and low sorting technology at the disposal site. Source separation system for organic household waste is the specific issue relating to the waste recycling and composting. It needs to be set as the top priority in waste management policy for the whole country.
3. From the results, approximately 60% by weight of fine fraction < 10 mm was found in the German MBT material. They help to save landfill space. Energy savings are achieved through materials recovery. While Luxembourg showed approximately 43% by weight of the same size of waste fraction. The trommel sieve size with the size of 150 mm does not help increase the small particle size of waste. Luxembourg should reduce the size of trommel sieve to increase amounts of biodegradable waste. Thai MBT material presents high amount of the coarse fraction > 40 mm. An

effort to increase screening facility in particular the proper size screening machine is an important factor to separate the recovery waste and biodegradable waste in the MBT system. Recycling technology is the best way to go compared others like pyrolysis and incinerator for the Thai waste in long term. In addition, the plastic bags have many decade participated in lifestyles of Thai urban people. To reduce the number of one way use throw away bags, they need to be replaced by stronger bags which may cost one time money to the person which is using it, but the shop will replace it for free when it is broken. No more give away plastic bags for free, cheap throw one way use plastic bags will decrease plastic bags production and makes recycling easier as there will be only one environmental kind of plastic used.

4. Pretreatment technology causes a strong reduction of all common negative environmental impacts (smell, leachate, methane, and unstable waste bodies) compared to untreated waste. It also gives so many advantages for helping to reduce climate change problems. It is a suitable solid waste management option and environmentally sound management for landfills worldwide. From the results in this study, the high reduced impact on leachate showed no significant difference between Europe and Southeast asian. With this as a reason, using that high cost MBT technology is not compatible with an effective waste and emissions reductions. Money and time savings could be achieved by implementing in a low cost MBT technology.

5. In comparison to untreated waste, particle size of MBT material is visibly smaller. Typical untreated waste is heterogenous. The treated waste is composed of dust to coarse fractions. Maximum particle size of pretreated waste is typically $<$ 100 mm. Primary components are compost, plastics, fibrous materials and inert (glass and ceramics). Percentage of each components greatly dependents on the MBT process of each country. Other characteristics are significantly reduced water content, reduced total organic carbon and reduced potential heavy metals.

   The geotechnical properties of the MBT material are improved compared to untreated waste:

   - more homogenous
   - more dense
   - better compact
   - lower permeability and
   - lot of water adsorbing material

   The utilization of MBT material in this study shows a good trend as it proved to be a safe material which contained very low amount of toxic contaminations from lead, cadmium and arsenic. The compost part can be developed to be a soil conditioner. It is also suitable utilized as bio filter layer in the final cover of landfill or as temporary cover during the MBT process.

Table 7.1: Summarized comparison of the MBT process and material characteristics

	Luxembourg	**Germany**	**Thailand**
Mechanical process	shredding, screening (ca.150 mm), magnetic separator homogenization with leachate	shredding, screening (ca.80 mm), magnetic separator, homogenization with leachate	shredding, no screening
Biological process	Single stage: aeration 18 – rotting tunnels with leachate recirculation duration (6 weeks)	Two stages: indoor aeration composting heaps or aeration rotting tunnels duration (3 – 5 week) outdoor aeration rotting heaps with or without turning machine duration (9 – 12 weeks)	Single stage: passive aeration chimney system trapezoidal composting windrow covered with coconut husks duration (9 months)
MBT material important characteristics	- fine fractions < 10 mm is less than Germany - component remains more like the fresh waste - lowest stabilized material - lots of light and thin plastics remain in compost - difficult to be compacted and become dense material	- highest percentage of fine fractions < 10 mm (60%) - none of paper and metals - dry and less smell of methane - water content is highly reduced - some amounts of light and thin plastics remain in compost - lower COD concentration than Luxembourg and Thailand	- highest percentage of coarse fractions > 40 mm (62%) - lots of plastic bags - less smell of methane - significant reduced respiration activity, TOC was reduced up to 8% - compost is all homogenous

Table 7.2: Summarized comparison of positive and negative aspects of the management and treatment systems

	Luxembourg	**Germany**	**Thailand**
Positive aspects	1. Facilities on waste collection are always available 2. Selective collection is very good organized 3. All waste is rapidly managed 4. High treatment capacity for waste	1. Legistrative prohibition is very effective nationwide 2. Selective collection and waste recycling are effective 3. Sorting technique is very effective 4. Significant reduced waste amount and landfill emissions 5. High treatment capacity for MSW 6. Energy recovery from MBT system is practiced	1. The most simplest method for MSW treatment 2. Cheapest environmentally sound technology 3. High stabilized MBT material 4. Significant reduced waste amount and landfill emissions
Negative aspects	1. High costs for operation & maintenance 2. Less efficiency in sorting technique, due to large size of trommel sieve 3. MBT material is less stabilized, due to short composting period	1. High costs for operation & facilities installation 2. Running costs for cleaning, facilities maintenance, and emissions treatment plant	1. High amounts of remaining non-recyclable waste in landfill 2. No promoting recycling behavior 3. Composting system takes lots of space and long duration

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Appendix A

Photographs

A.1: Photographs of waste samples

A.2: Photograph of geotechnical equipments

A.1 Photographs of waste samples

Luxembourg

Figure A.1: The waste sample 1 (not sieved) from Muertendall was deposited before 1990. It has been covered with soil clay layer, thickness of 0.8 m. The sample has been taken out at the depth of 2.5 m. It was black and no smell of methane. The stabilized material has been noticed and documented.

Figure A.2: The waste (6 – 10 years), (not sieved) the smell of methane is produced as a result of anaerobic process, is an indication for insufficient aeration.

Luxembourg

Figure A.3: The waste (1–2 years), (not sieved) the smell of methane was stronger. The waste sample contained living micro-organisms such as fungi and worms

Figure A.4: The final MBT waste, 6 weeks (not sieved) from Fridhaff. The waste was moist, less smell of methane. They contained various kinds of waste component.

Germany

Figure A.5: The MBT waste, 20 weeks (not sieved) from Eiterköpfe. The waste was very dry, less smell, its color was brown and black. Not found composition of paper or large particles of plastics. They contained mostly of compost, seeds and corks.

Figure A.6: The MBT waste, 40 weeks (not sieved) from Eiterköpfe. The waste was moist, the color was completely black, less smell. The fine particle was cogging. There was no proportion of the large particle size of more than 40 mm.

Germany

Figure A.7: The MBT waste, 25 weeks (not sieved) was stabilized and dry, less smell of methane. Its color was brown and black.

Figure A.8: The MBT waste, 35 weeks (not sieved) was dry, stabilized and less smell of methane. Its color was black.

Germany

Figure A.9: The MBT waste, 15 weeks (not sieved) from Singhofen was very dry, less smell. Fine fraction could be seen by eyes.

Thailand

Figure A.10: The MBT waste, 48 weeks (not sieved) from Thailand were moist, black and less smell. They contained mostly of small and middle size of plastics bags.

A.2 Photographs of geotechnical equipments

Figure A.11: MBT sample < 10 mm on extruder with manual hydraulic jack

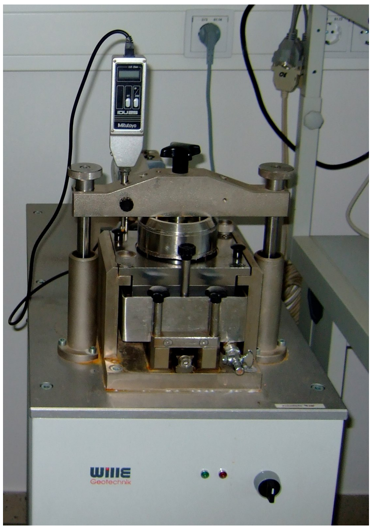

Figure A.12: A direct shear strength equipment

A.3 Photographs of waste containers

- Figure A.13: Public waste container in Luxembourg
- Figure A.14: Public waste container in Germany
- Figure A.15: Public waste container in Thailand

Figure A.13: Public waste bin for 4 types of waste: glass, paper, packaging and residue waste in Luxembourg

Figure A.14: Public waste bin for 4 types of waste: glass, paper, packaging and residue waste in Germany

Figure A.15: Three colors waste bins for dry waste, wet waste and packaging in Bangkok, Thailand

Appendix B

Laboratory records

- B.1 : Three size fractions analysis
- B.2 : Particle size distribution of MBT materials
- B.3 : Particle size distribution of small size < 10 mm
- B.4 : Compaction test
- B.5 : Shear strength test
- B.6 : Permeability test
- B.7 : Porosity test
- B.8 : Eluate quality test

B.1 Three size fractions analysis

Muertendall (Luxembourg)

Table B.1: Three size fractions analysis for Muertendall (redeposited waste)

Sieve opening	Sieve analysis			Remark
	weight retained	percentage retained		
(mm)	(g)	ind. %	cum. %	
> 40	29.29	1.26	1.26	-
10 – 40	1345.6	58.07	59.33	-
< 10	942.3	40.67	100	-
Total weight	2317.19	100	-	-

ind. percent retained (%) = (wt retained on a sieve / total dry wt) x 100
cum.percent retained (%) = ind. (%) retained + cum.(%) retained of previous sieve

Table B.2: Three size fractions analysis for Muertendall waste (6 – 10 years)

Sieve opening	Sieve analysis			Remark
	weight retained	percentage retained		
(mm)	(g)	ind. %	cum. %	
> 40	1301.3	53.57	53.57	-
10 – 40	558.46	22.99	76.56	-
< 10	569.3	23.44	100	-
Total weight	2429.06	100	-	-

ind. percent retained (%) = (wt retained on a sieve / total dry wt) x 100
cum.percent retained (%) = ind. (%) retained + cum.(%) retained of previous sieve

Table B.3: Three size fractions analysis for Muertendall waste (1 – 2 years)

Sieve opening	Sieve analysis			Remark
	weight retained	percentage retained		
(mm)	(g)	ind. %	cum. %	
> 40	1043.5	50.17	50.17	-
10 – 40	549.60	26.42	76.59	-
< 10	486.96	23.41	100	-
Total weight	2080.06	100	-	-

ind. percent retained (%) = (wt retained on a sieve / total dry wt) x 100
cum.percent retained (%) = ind. (%) retained + cum.(%) retained of previous sieve

Fridhaff (Luxembourg)

Table B.4: Three size fractions analysis for Fridhaff MBT waste (6 weeks)

Sieve opening	Sieve analysis			Remark
	weight retained	percentage retained		
(mm)	(g)	ind. %	cum. %	
> 40	1677	23.0	22.97	-
10 – 40	2459	33.7	56.6	-
< 10	3165	43.4	100	-
Total weight	7301	100	-	-

ind. percent retained (%) = (wt retained on a sieve / total dry wt) x 100
cum.percent retained (%) = ind. (%) retained + cum.(%) retained of previous sieve

Linkenbach (Germany)

Table B.5: Three size fractions analysis for Linkenbach MBT waste (25 weeks)

Sieve opening	Sieve analysis			Remark
	weight retained	percentage retained		
(mm)	(g)	ind. %	cum. %	
> 40	216.14	4.84	4.84	-
10 – 40	1556	34.82	39.66	-
< 10	2696	60.34	100	-
Total weight	4468.14	100	-	-

Table B.6: Three size fractions analysis for Linkenbach MBT waste (35 weeks)

Sieve opening	Sieve analysis			Remark
	weight retained	percentage retained		
(mm)	(g)	ind. %	cum. %	
> 40	229.66	4.77	4.77	-
10 – 40	1280.36	26.59	31.36	-
< 10	3304.3	68.64	100	-
Total weight	4814.32	100	-	-

ind. percent retained (%) = (wt retained on a sieve / total dry wt) x 100
cum.percent retained (%) = ind. (%) retained + cum.(%) retained of previous sieve

Eiterköpfe (Germany)

Table B.7: Three size fractions analysis for Eiterköpfe MBT waste (20 weeks)

Sieve opening	Sieve analysis			Remark
	weight retained	percentage retained		
(mm)	(g)	ind. %	cum. %	
> 40	280.6	5.41	5.41	-
10 – 40	2049.2	39.48	44.89	-
< 10	2860.8	55.11	100	-
Total weight	5190.6	100	-	-

Table B.8: Three size fractions analysis for Eiterköpfe MBT waste (40 weeks)

Sieve opening	Sieve analysis			Remark
	weight retained	percentage retained		
(mm)	(g)	ind. %	cum. %	
> 40	-	-	-	-
10 – 40	963	33.24	33.24	-
< 10	1934	66.76	100	-
Total weight	2897	100	-	-

ind. percent retained (%) = (wt retained on a sieve / total dry wt) x 100
cum.percent retained (%) = ind. (%) retained + cum.(%) retained of previous sieve

Singhofen (Germany)

Table B.9: Three size fractions analysis for Singhofen MBT waste (15 weeks)

Sieve opening	Sieve analysis			Remark
	weight retained	percentage retained		
(mm)	(g)	ind. %	cum. %	
> 40	560	14.08	14.08	-
10 – 40	1036	26.06	40.14	-
< 10	2380	59.86	100	-
Total weight	3976	100	-	-

ind. percent retained (%) = (wt retained on a sieve / total dry wt) x 100
cum.percent retained (%) = ind. (%) retained + cum.(%) retained of previous sieve

Table B.10: Three size fractions analysis for Phitsanulok MBT waste (48 weeks)

Sieve opening	Sieve analysis			Remark
	weight retained	percentage retained		
(mm)	(g)	ind. %	cum. %	
> 40	14600	62.39	62.39	-
10 – 40	5400	23.08	85.47	-
< 10	3400	14.53	100	-
Total weight	23400	100	-	-

ind. percent retained (%) = (wt retained on a sieve / total dry wt) x 100
cum.percent retained (%) = ind. (%) retained + cum.(%) retained of previous sieve

B.2 Particle size distribution of MBT materials

Luxembourg

Table B.11: Particle size distribution for sample from Luxembourg (6 weeks)

Sieve opening	weight retained	weight retained	Cumulative %	Cumulative %
(mm)	g	%	Retained	Passing
100	0	0	0	100
90	1072	15	15	85
40	605	8	23	77
30	616	8	31	69
20	1151	16	47	53
10	692	9	57	43
8	456	6	63	37
6.3	321	4	67	33
4	591	8	75	25
2	765	10	86	14
1	342	5	91	9
0.5	441	6	97	3
Pan	249	3	-	-
Total weight	7301	100	-	-

ind. percent retained (%) = (wt retained on a sieve / total dry wt) x 100 cum. percent retained (%) = ind. percent retained + cum. percent retained of previous sieve

D_{10} = the size of sieve at 10 percent passing = 1.1
D_{30} = the size of sieve at 30 percent passing = 5.0
D_{60} = the size of sieve at 60 percent passing = 25

$$C_u = \frac{D_{60}}{D_{10}} = \frac{25}{1.1} = 22.72$$

$$C_c = \frac{(D_{30})^2}{D_{10} * D_{60}} = \frac{(5.0)^2}{1.1 * 25} = 0.91$$

Germany

Table B.12: Particle size distribution for sample from Germany (15 weeks)

Sieve opening	weight retained	weight retained	Cumulative %	Cumulative %
(mm)	g	%	Retained	Passing
100	0	0	0	100
90	0	0	0	100
40	560	14	14	86
30	321	8	22	78
20	440	11	33	67
10	275	7	40	60
8	176	4	45	55
6.3	176	4	49	51
4	350	9	58	42
2	550	14	72	28
1	400	10	82	18
0.5	520	13	95	5
Pan	208	5	-	-
Total weight	3976	100	-	-

ind. percent retained (%) = (wt retained on a sieve / total dry wt) x 100 cum. percent retained (%) = ind. percent retained + cum. percent retained of previous sieve

D_{10} = the size of sieve at 10 percent passing = 0.65
D_{30} = the size of sieve at 30 percent passing = 2.2
D_{60} = the size of sieve at 60 percent passing = 10

$$C_u = \frac{D_{60}}{D_{10}} = \frac{10}{0.65} = 15.38$$

$$C_c = \frac{(D_{30})^2}{D_{10} * D_{60}} = \frac{(2.2)^2}{0.65 * 10} = 0.74$$

Thailand

Table B.13: Particle size distribution for sample from Thailand (48 weeks)

Sieve opening (mm)	weight retained g	weight retained %	Cumulative % Retained	Cumulative % Passing
100	0	0	0	100
90	8900	38	38	62
40	5700	24	62	38
30	1470	6	69	31
20	1630	7	76	24
10	2300	10	85	15
8	0	0	85	15
6.3	210	1	86	14
4	360	2	88	12
2	900	4	92	8
1	700	3	95	5
0.5	700	3	98	2
Pan	530	2	-	-
Total weight	23400	100	-	-

ind. percent retained (%) = (wt retained on a sieve / total dry wt) x 100 cum. percent retained (%) = ind. percent retained + cum. percent retained of previous sieve

D_{10} = the size of sieve at 10 percent passing = 2.6
D_{30} = the size of sieve at 30 percent passing = 28
D_{60} = the size of sieve at 60 percent passing = 80

$$C_u = \frac{D_{60}}{D_{10}} = \frac{80}{2.6} = 30.76$$

$$C_c = \frac{(D_{30})^2}{D_{10} * D_{60}} = \frac{(28)^2}{2.6 * 80} = 3.76$$

B.3 Particle size distribution of small size < 10 mm

Luxembourg < 10 mm

Table B.14: Particle size distribution of small size, Luxembourg

Sieve opening	weight retained	weight retained	Cumulative %	Cumulative %
(mm)	g	%	Retained	Passing
8	456	14	14	86
6.3	321	10	24	76
4	591	19	43	57
2	765	24	67	33
1	342	11	78	22
0.5	441	14	92	8
Pan	249	8	-	-
Total weight	3165	100	-	-

D_{10} = the size of sieve at 10 percent passing = 0.6
D_{30} = the size of sieve at 30 percent passing = 1.8
D_{60} = the size of sieve at 60 percent passing = 4.1

$$C_u = \frac{D_{60}}{D_{10}} = \frac{4.1}{0.6} = 6.83$$

$$C_c = \frac{(D_{30})^2}{D_{10} * D_{60}} = \frac{(1.8)^2}{0.6 * 4.1} = 1.31$$

Germany < 10 mm

Table B.15: Particle size distribution of small size, Germany

Sieve opening (mm)	weight retained g	weight retained %	Cumulative % Retained	Cumulative % Passing
8	176	7	7	93
6.3	176	7	14	86
4	350	15	29	71
2	550	23	52	48
1	400	17	69	31
0.5	520	22	91	9
Pan	208	9	-	-
Total weight	2380	100	-	-

D_{10} = the size of sieve at 10 percent passing = 0.51
D_{30} = the size of sieve at 30 percent passing = 0.95
D_{60} = the size of sieve at 60 percent passing = 2.9

$$C_u = \frac{D_{60}}{D_{10}} = \frac{2.9}{0.51} = 5.68$$

$$C_c = \frac{(D_{30})^2}{D_{10} * D_{60}} = \frac{(0.95)^2}{0.51 * 2.9} = 0.60$$

Thailand < 10 mm

Table B.16: Particle size distribution of small size, Thailand

Sieve opening	weight retained	weight retained	Cumulative %	Cumulative %
(mm)	g	%	Retained	Passing
8	0	0	0	100
6.3	210	6	6	94
4	360	11	17	83
2	900	26	43	57
1	700	21	64	36
0.5	700	21	84	16
Pan	530	16	-	-
Total weight	3400	100	-	-

D_{10} = the size of sieve at 10 percent passing = 0.42
D_{30} = the size of sieve at 30 percent passing = 0.8
D_{60} = the size of sieve at 60 percent passing = 2.4

$$C_u = \frac{D_{60}}{D_{10}} = \frac{2.4}{0.42} = 5.71$$

$$C_c = \frac{(D_{30})^2}{D_{10} * D_{60}} = \frac{(0.8)^2}{0.42 * 2.4} = 0.63$$

B.4 Compaction test

- **Luxembourg**

Compaction test's parameters
Average maximum dry density (estimated) = 0.78 t/m^3 SD = 0.03
Average optimum moisture content (estimated) = 52% , SD = 3.09

Table B.17: Proctor density of small size, Luxembourg

Compacted sample No.	1	2	3	4	5
Actual average water content %	38	46	50	55	83
Mass of compacted sample and mold (g)	3384	3483	3614	3706	3686
Mass of mold (g)	2438	2438	2438	2438	2438
Wet mass of sample in mold (g)	946	1045	1176	1268	1248
Wet density ρ (g/cm^3)	1	1.11	1.25	1.34	1.32
Dry density ρ_d (g/cm^3)	0.74	0.77	0.82	0.78	0.72
Compacted sample No.	1	2	3	4	5
Actual average water content %	36	47	56	60	79
Mass of compacted sample and mold (g)	3351	3525	3642	3681	3630
Mass of mold (g)	2438	2438	2438	2438	2438
Wet mass of sample in mold (g)	913	1087	1204	1243	1192
Wet density ρ (g/cm^3)	0.97	1.15	1.28	1.32	1.26
Dry density ρ_d (g/cm^3)	0.75	0.77	0.74	0.77	0.66
Compacted sample No.	1	2	3	4	5
Actual average water content %	30	39	49	58	78
Mass of compacted sample and mold (g)	3350	3545	3636	3728	3650
Mass of mold (g)	2438	2438	2438	2438	2438
Wet mass of sample in mold (g)	912	1107	1198	1290	1212
Wet density ρ (g/cm^3)	0.97	1.17	1.27	1.37	1.29
Dry density ρ_d (g/cm^3)	0.75	0.78	0.78	0.77	0.69
Average wet density ρ (g/cm^3)	0.98	1.14	1.26	1.34	1.29
Average dry density ρ_d (g/cm^3)	0.75	0.77	0.78	0.77	0.69
Average water content (%)	35	44	52	58	80

- **Germany**

Compaction test's parameters
Average maximum dry density (estimated) = 1.04 t/m^3 SD = 0.03
Average optimum moisture content (estimated) = 42% , SD = 2.16

Table B.18: Proctor density of small size, Germany

Compacted sample No.	1	2	3	4	5	6
Actual average water content %	25	30	30	40	47	49
Mass of compacted sample and mold (g)	3432	3602	3608	3755	3750	3705
Mass of mold (g)	2438	2438	2438	2438	2438	2438
Wet mass of sample in mold (g)	994	1164	1170	1317	1312	1267
Wet density ρ (g/cm^3)	1.05	1.23	1.24	1.4	1.39	1.34
Dry density ρ_d (g/cm^3)	0.84	0.95	0.95	1	0.95	0.9
Compacted sample No.	1	2	3	4	5	6
Actual average water content %	25	26	33	41	45	50
Mass of compacted sample and mold (g)	3528	3530	3720	3836	3819	3758
Mass of mold (g)	2438	2438	2438	2438	2438	2438
Wet mass of sample in mold (g)	1090	1092	1282	1398	1381	1320
Wet density ρ (g/cm^3)	1.16	1.16	1.36	1.48	1.46	1.4
Dry density ρ_d (g/cm^3)	0.92	0.92	1.02	1.05	1.01	0.93
Compacted sample No.	1	2	3	4	5	6
Actual average water content %	25	33	40	45	42	51
Mass of compacted sample and mold (g)	3320	3590	3794	3897	3865	3840
Mass of mold (g)	2438	2438	2438	2438	2438	2438
Wet mass of sample in mold (g)	882	1152	1356	1459	1427	1402
Wet density ρ (g/cm^3)	0.94	1.22	1.44	1.55	1.51	1.49
Dry density ρ_d (g/cm^3)	0.75	0.92	1.03	1.07	1.07	0.98
Average wet density ρ (g/cm^3)	1.05	1.2	1.35	1.48	1.46	1.41
Average dry density ρ_d (g/cm^3)	0.84	0.93	1	1.04	1.01	0.94
Average water content (%)	25	30	35	42	45	50

- **Thailand**

Compaction test's parameters
Average maximum dry density (estimated) = 0.98 t/m^3 SD = 0
Average optimum moisture content (estimated) = 33% , SD = 0

Table B.19: Proctor density of small size, Thailand

Compacted sample No.	1	2	3	4	5	6
Actual average water content %	25	30	33	40	50	60
Mass of compacted sample and mold (g)	3539	3614	3660	3694	3832	3828
Mass of mold (g)	2438	2438	2438	2438	2438	2438
Wet mass of sample in mold (g)	1101	1176	1222	1256	1394	1390
Wet density ρ (g/cm^3)	1.17	1.25	1.3	1.33	1.48	1.47
Dry density ρ_d (g/cm^3)	0.94	0.96	0.97	0.95	0.92	0.92
Compacted sample No.	1	2	3	4	5	6
Actual average water content %	29	28	33	41	49	55
Mass of compacted sample and mold (g)	3564	3605	3678	3698	3744	3743
Mass of mold (g)	2438	2438	2438	2438	2438	2438
Wet mass of sample in mold (g)	1126	1167	1240	1260	1306	1305
Wet density ρ (g/cm^3)	1.19	1.24	1.31	1.34	1.38	1.38
Dry density ρ_d (g/cm^3)	0.93	0.97	0.99	0.95	0.93	0.89
Compacted sample No.	1	2	3	4	5	6
Actual average water content %	29	33	33	40	50	55
Mass of compacted sample and mold (g)	3578	3642	3680	3699	3745	3740
Mass of mold (g)	2438	2438	2438	2438	2438	2438
Wet mass of sample in mold (g)	1140	1204	1242	1261	1307	1302
Wet density ρ (g/cm^3)	1.21	1.28	1.32	1.34	1.39	1.38
Dry density ρ_d (g/cm^3)	0.94	0.96	0.99	0.96	0.92	0.89
Average wet density ρ (g/cm^3)	1.19	1.25	1.31	1.34	1.42	1.41
Average dry density ρ_d (g/cm^3)	0.93	0.96	0.98	0.95	0.92	0.9
Average water content (%)	28	30	33	40	50	57

B.5 Shear strength test

- **Luxembourg**
  Shear strength's parameters
  Average angle of internal friction (φ) = 36.45 °, SD = 0.83
  Average cohesion (c) = 12.83 kN/m^2 , SD = 1.36
  Average initial water content of samples = 47%

Table B.20: Shear strength of small size, Luxembourg

Test No.	Normal stress	Shear stress	Failure distance	Conso.force
	kN/m^2	kN/m^2	mm	kN/m^2
1.1	20	27	19.94	5
1.2	40	48	19.37	5
1.3	80	73	17.69	5
1.4	100	91	18.51	5
2.1	20	24	19.42	5
2.2	40	42	19.89	5
2.3	80	69	19.37	5
2.4	100	82	19.24	5

- **Germany**
  Shear strength's parameters
  Average angle of internal friction (φ) = 38.63 °, SD = 0.7
  Average cohesion (c) = 9.00 kN/m^2 , SD = 0.22
  Average initial water content of samples = 50%

Table B.21: Shear strength of small size, Germany

Test No.	Normal stress	Shear stress	Failure distance	Conso.force
	kN/m^2	kN/m^2	mm	kN/m^2
1.1	20	24.43	19.98	5
1.2	40	47.57	19.98	5
1.3	80	65.02	18.06	5
1.4	100	96.18	16.49	5
2.1	20	23.13	20.02	5
2.2	40	40.67	20.02	5
2.3	80	77.50	19.32	5
2.4	100	82.65	19.99	5

- **Thailand**
  Shear strength's parameters
  Average angle of internal friction (φ) = 31.87 °, SD = 0.37
  Average cohesion (c) = 5.42 kN/m^2 , SD = 0.2
  Average initial water content of samples = 55%

Table B.22: Shear strength of small size, Thailand

Test No.	Normal stress	Shear stress	Failure distance	Conso.force
	kN/m^2	kN/m^2	mm	kN/m^2
1.1	20	17.89	19.31	5
1.2	40	31.07	15.51	5
1.3	80	56.91	14.39	5
1.4	100	68.08	18.61	5
2.1	20	17.19	18.99	5
2.2	40	29.50	19.89	5
2.3	80	56.03	19.14	5
2.4	100	65.20	11.49	5

B.6 Permeability test

Falling Head Test procedure

1. The MBT material with the size of a diameter < 10 mm was placed into a PVC test cylinder having a height of 30 cm and diameter equal to 10 cm. A compaction was made following the standard compaction test. The mold was filled with three layers of MBT material and each layer is subjected to 25 drops of the hammer. The specimen was fully saturated into the water.

2. Water was gently filled into the test cylinder on top of the specimen. When the top of the test cylinder was completely full and the system was well set, the time of measuring started. The coefficient of permeability can be computed using following equation.

$$k = \left(\frac{aL}{At}\right) ln \left(\frac{h_1}{h_3}\right) \tag{B.1}$$

Where:

a = area of falling head tube (cm^2)

h_1 = initial drop height (cm)

h_3 = final drop height (cm)

t = time (sec)

L = length of specimen (cm)

A = area of specimen (cm^2)

k = coefficient hydraulic conductivity (m/sec)

- **Luxembourg**

Length of the specimen, L (cm) = 10
Area of the specimen, A (cm^2) = 70.85
Area of falling head tube, a (cm^2) = 70.85

Table B.23: Permeability of small size, Luxembourg

1		time (sec)	k (m/s)
h1 (cm) =	20	0	-
h2 (cm) =	19.5	3600	7.0 x 10^{-7}
h3 (cm) =	19.4	7200	4.23 x 10^{-7}
h4 (cm) =	18.9	10800	5.23 x 10^{-7}
Average			5.48 x 10^{-7}
2		time (sec)	k (m/s)
h1 (cm) =	20	0	-
h2 (cm) =	19	3600	1.42 x 10^{-6}
h3 (cm) =	18.9	7200	7.85 x 10^{-7}
h4 (cm) =	18	10800	9.75 x 10^{-7}
Average			1.06 x 10^{-6}
3		time (sec)	k (m/s)
h1 (cm) =	20	0	-
h2 (cm) =	18.9	3600	1.57 x 10^{-6}
h3 (cm) =	18.9	7200	7.85 x 10^{-7}
h4 (cm) =	18.8	10800	5.7 x 10^{-7}
Average			7.61 x 10^{-7}

Permeability's parameters

Estimated saturated hydraulic conductivity value (k)

= 7.71 x 10^{-7} (m/s) , SD = 3.33 x 10^{-7}

Estimated water content after saturation

= 67% , SD = 7.7

- **Germany**

Length of the specimen, L (cm) = 10
Area of the specimen, A (cm^2) = 70.85
Area of falling head tube, a (cm^2) = 70.85

Table B.24: Permeability of small size, Germany

1		time (sec)	k (m/s)
h1 (cm) =	20	0	-
h2 (cm) =	19.9	18000	2.78 x 10^{-8}
h3 (cm) =	19.9	36000	1.39 x 10^{-8}
h4 (cm) =	19.9	54000	9.28 x 10^{-9}
Average			1.69 x 10^{-8}
2		time (sec)	k (m/s)
h1 (cm) =	20	0	-
h2 (cm) =	19.9	18000	2.78 x 10^{-8}
h3 (cm) =	19.8	36000	2.79 x 10^{-8}
h4 (cm) =	19.7	39600	3.81 x 10^{-8}
Average			3.12 x 10^{-8}
3		time (sec)	k (m/s)
h1 (cm) =	20	0	-
h2 (cm) =	19.9	54000	9.28 x 10^{-9}
h3 (cm) =	19.9	57600	8.70 x 10^{-9}
h4 (cm) =	19.8	69400	1.36 x 10^{-8}
Average			1.05 x 10^{-8}

Permeability's parameters

Estimated saturated hydraulic conductivity value (k)

= 1.95 x 10^{-8} (m/s) , SD = 8.65 x 10^{-9}

Estimated water content after saturation

= 56% , SD = 8.05

- **Thailand**

Length of the specimen, L (cm) = 10
Area of the specimen, A (cm^2) = 70.85
Area of falling head tube, a (cm^2) = 70.85

Table B.25: Permeability of small size, Thailand

1		time (sec)	k (m/s)
h1 (cm) =	20	0	-
h2 (cm) =	19.9	54000	9.28 x 10^{-9}
h3 (cm) =	19.9	86400	5.80 x 10^{-9}
Average			7.54 x 10^{-9}
2		time (sec)	k (m/s)
h1 (cm) =	20	0	-
h2 (cm) =	19.9	54000	9.2 x 10^{-9}
h3 (cm) =	19.9	69400	7.2 x 10^{-9}
Average			8.20 x 10^{-9}
3		time (sec)	k (m/s)
h1 (cm) =	20	0	-
h2 (cm) =	19.9	54000	9.28 x 10^{-9}
h3 (cm) =	19.9	57600	8.70 x 10^{-9}
h4 (cm) =	19.9	69400	7.22 x 10^{-9}
Average			8.40 x 10^{-9}

Permeability's parameters

Estimated saturated hydraulic conductivity value (k)

= 8.04 x 10^{-9} (m/s) , SD = 3.67 x 10^{-10}

Estimated water content after saturation

= 48% , SD = 3.81

B.7 Porosity test

Determination of void ratio e (given in decimal)

$$e = \frac{V_v}{V_s} = \frac{n}{1-n}$$

Where:

e = void ratio (given in decimal)
n = porosity (given in percent)
V_s= volume of solid particles
V_v= total volume of voids

Determination of porosity n (given in percent)

$$n = \frac{V_v}{V_t} = \frac{e}{1+e}$$

Where:

n = porosity (given in percent)
e = void ratio (given in decimal)
V_s= volume of solid particles
V_v= total volume of voids

Table B.26: Porosity of MBT materials < 10 mm

Sample	Volume of sample mL V_s	Volume of void mL V_v	Void ratio e	Porosity %
LU<10 mm				
1	40	12	0.3	23.07
2	40	11	0.27	21.56
3	40	11.5	0.29	22.48
Average		11.5	0.28	22.37±0.76
LU <4 mm				
1	40	19	0.47	31.97
2	40	15	0.37	27
3	40	11.5	0.29	22.48
Average		15.16	0.37	27.15±4.75
LU <1 mm				
1	40	22.5	0.56	35.89
2	40	20	0.50	33.33
3	40	25	0.62	38.27
Average		22.5	0.56	35.83±2.47
DE <10 mm				
1	40	15	0.37	27
2	40	14	0.35	25.9
3	40	10.6	0.26	20.95
Average		13.2	0.33	24.62±3.22
DE <4 mm				
1	40	16	0.4	28.57
2	40	18	0.45	31
3	40	19	0.47	31.97
Average		17.6	0.44	30.5±1.75
DE <1 mm				
1	40	21	0.52	34.2
2	40	25	0.62	38.27
3	40	29.5	0.74	42.5
Average		25.1	0.62	38.32±4.15
TH <10 mm				
1	40	17	0.42	29.6
2	40	18	0.45	31
3	40	18	0.45	31
Average		17.6	0.44	30.53±0.81
TH <4 mm				
1	40	33	0.82	45.05
2	40	30	0.75	42.8
3	40	29.5	0.74	42.5
Average		30.8	0.77	43.45±1.39
TH <1 mm				
1	40	35	0.87	46.5
2	40	32	0.8	44.4
3	40	30	0.75	42.8
Average		32.3	0.8	44.57±1.86

Table B.27: Extracted eluate of MBT samples quality tests

Parameters	Unit	Luxembourg		Germany		Thailand	
		Range	Average	Range	Average	Range	Average
COD	mg/L	3,438 – 3,750	3,631±137.7	1,875 – 2,411	2,185±219.8	2,679 – 2,991	2,783±147
NH_4^+	mg/L	16.29 – 22.43	19.91±2.6	20.54 – 21.95	21.09 ±0.6	21.95 – 33.29	29.35 ±5.4
SO_4^{2-}	mg/L	525 – 1,250	866.67±297	700 – 1,350	1,041.67±266	1,375 – 1,800	1,633±185
Cl^-	mg/L	575 – 700	616.67±58.9	575 – 775	675±81.6	575 – 650	608.3±31.1
Pb	mg/L	0.122 – 0.331	0.252±0.09	0.203 – 0.386	0.295 ±0.07	0.157 – 0.269	0.220±0.04
Cd	mg/L	0.002 – 0.004	0.003±0.0008	0.003 – 0.005	0.004±0.0009	0.004	0.004±0
As	mg/L	ND	ND	ND	ND	ND	ND

Appendix C

Glossary of Terms

Absorptive capacity The maximum amount of liquid which can be taken up and retained by unit weight of solid under specified conditions; usually the amount of liquid retained by unit weight of refuse in a landfill before leachate is produced.

Active venting (Landfill gas) The systematic provision of vents in landfill sites to enable landfill gas to escape into the atmosphere as it is generated. Active venting is so named mechanical assistance is used to enable positive extraction of gas.

Adsorption Adsorption is the accumulation or concentration of substances at a surface or interface.

Aeration The process of exposing a bulk material, such as compost or solid waste in a landfill, to intimate contact with air, or of charging a liquid with air. Several methods may be used, e.g. forcing air into the material or through the liquid, or agitating the liquid to promote surface adsorption of air.

Aerobic zone The area within a landfill into which air has penetrated, allowing aerobic decomposition of the fill material to proceed.

Aftercare The maintenance work needed to ensure that a restored landfill site does not produce environmental problems.

Afteruse The use to which a landfill site is put following its restoration.

Analysis (Solid waste) The determination of the types and proportions of the various materials comprising a given sample of solid waste. Recommended procedures for carrying out some solid waste analyses are available.

Biodegradable Waste is a compound that can be degraded or converted to simpler compounds by micro-organisms.

Biodegradation It is another of the principal processes by which soil affects waste stream purification and a number of studies have been made on the biological degradability or organic absorbed by soils. Soils, particularly the surface horizon to a depth of one to three feet, contain tremendous numbers and varieties of aerobic, facultative and obligate anaerobic organisms which singly, or together, can degrade all but the most refractory organic substances.

Biogas Gas formed by anaerobic digestion or organic material, e.g. whey, sewage sludge, or landfill gas. Typical composition 62% methane, 38% carbon dioxide, can be used for heat and power purposes since spark ignition engines and gas turbines can be modified to use it as a fuel.

Biologically stabilised The state where a system has completely degraded its nutrient source biologically to produce an inactive medium, which is no longer capable of supporting growth.

Clay That portion of a soil having a particle size of less than 0.002 mm.

Compaction Reduction in bulk of fill by rolling and tamping.

Composting The biological breakdown of organic solids in order to stabilise them, producing a humic substance valuable in some circumstances as a soil conditioner.

Compost A combination of decomposed plant and animal materials and other organic materials that are being decomposed largely through aerobic decomposition into a rich black soil.

Compost (Thai definition) A transformed organic component by the biological decomposition process, the product is quite stable, brown to black in color, like humus, small particle size and not unpleasure smells PCD [2005].

Decomposition The breakdown of organic wastes by bacteria, chemical or thermal means. Complete chemical oxidation leaves only carbon dioxide, water and inorganic solids.

Degradation A particular type of gradual decomposition that usually proceeds in well-defined stages to give products with fewer carbon atoms than the original compound. The term is often applied to decomposition resulting from the action of micro-organisms.

Disposal The activities associated with the long-term handling of:
(i) Solid waste that are collected and of no further use;
(ii) The residual matter after solid wastes have been processed and the recovery of conversion products or energy has been accomplished. Normally disposal is accomplished by means of sanitary landfilling.

Disposal facility A site or plant where waste may be deposited for treatment or final disposal.

Emission The amount of pollutant discharged per unit time. Or the amount of pollutant per unit volume of gas, or liquid, emitted.

Environment includes:
(i) ecosystems, including people and communities; and
(ii) all natural and physical resources; and
(iii) those qualities and characteristics of an area that contribute to the community reasonable enjoyment; and
(iv) the cultural, economic, aesthetic and social conditions that affect the above.

Ferrous metals A term used to describe iron and its alloys, e.g. steels. It is also used to describe the general class of metallic materials containing iron, cobalt, and nickel as major components.

Garbage Solid domestic waste, predominantly food waste.

Geomembrane A polymeric sheet material that is impervious to liquid than a geomembrane, but more resistant to penetration damage.

Heavy metals A term for those ferrous and non-ferrous metals having a density greater than about four which possess properties which may be hazardous in the environment. The term usually includes the metals copper, nickel, zinc, chromium, cadmium, mercury, lead and arsenic and may include selenium and others.

Hydraulic gradient Hydraulic head, relating to water in an aquifer, is the energy per unit weight of water. Hydraulic gradient is the difference in hydraulic head divided by the distance along the fluid flow path. Thus groundwater moves through an aquifer from a high inflow head to a lower outflow head: that is, in the direction of the hydraulic gradient.

Infiltration The downward movement of water through the soil.

Landfill The engineered deposit of waste on to and into land in such a way that pollution or harm to the environment is prevented and through restoration, land provided which may be used for another purpose.

Landfill gas A by-product from the digestion by anaerobic bacteria of putrescible matter.

Landfill gas migration The migration of landfill gas from the wastes mass. Gas migration regimes in and around landfills are a necessary part of the engineering and operation of landfill sites owing to the explosive nature of the gas. Computer-aided gas migration models to predict migration routes are being developed, which are likely to depend on an empirical rate of gas production.

Leachate Liquid emanating from a land disposal site that contains dissolved, suspended and/or microbial contaminants from the solid waste.

Leachate collection The collection by active pumping or passive drainage methods of water contaminated with the breakdown products of waste degradation processes from within and around the edges of landfill disposal sites.

Leachate recirculation (Leachate recycle) The practice of returning leachate, usually by direct spraying, to the upper layers of the landfill from which it has been abstracted.

Leachate treatment A process to reduce the polluting potential of leachate.

Liner A natural or synthetic membrane material used to line the base and sides of a landfill site to prevent leachate seeping into surrounding geological strata.

Magnetic separator An electro-mechanical means of separating ferrous materials from other materials.

Membrane Often used to describe man-made landfill site liners and similar materials used for other purposes in site engineering works.

Membrane barrier Thin layer or thickness of material impervious to the flow of gas or water.

Methane An odourless, colourless and asphyxiating gas that can explode under certain circumstances, and that can be produced by solid wastes undergoing anaerobic decomposition.

Micro-organisms Generally, any living thing, microscopic in size and including bacteria, yeasts, simple fungi, some algae, slime moulds and protozoans. They are involved in stabilization of wastes (composting) and in sewage treatment processes.

Municipal solid waste (MSW) Solid waste from households include similar waste which originated from commerce, trade, small businesses, office buildings and institutions (schools, hospitals, government buildings), waste from selected municipal services, i.e. waste from park and garden maintenance, waste from street cleaning services (street sweepings, the content of litter containers, market cleansing waste), bulky waste (e.g. white goods, old furniture, mattresses); and yard waste, leaves, grass clippings, the content of litter containers, and market cleansing waste EU [2006].

Permeability A measure of the rate at which a fluid will pass through a medium. The coefficient of permeability of a given fluid is an expression of the rate of flow through unit area and thickness under unit differential pressure at a given temperature. Synonymous with hydraulic conductivity when the fluid is water or an aqueous solution.

Organic materials Chemical compounds of carbon combined with other chemical elements and generally manufactured in the life processes of plants and animals. Most organic compounds are a source of food for bacteria and are usually combustible.

Recyclable waste Materials which can reuse such as glass, paper, metal, plastic, textiles and electronics or go to the processing used materials into new products.

Recycling The reuse of materials, not necessarily in their original form. Recycling may fall into any of the following classes:

(i) the direct use of a product more than once for the same purpose for which it was originally designed (eg. the glass milk bottle, the compressed gas cylinder) – reuse.

(ii) the use of a product in its original form, but for another purpose (eg. the 200 litre drum) – reuse.

(iii) the return of production line process wastes into main stream production line feedstock (eg. sprue from the manufacture of plastics) – direct recycling.

(iv) the treatment and reconstitution of the materials from one product to produce secondary raw materials for other products – indirect recycling.

(v) the conversion of wastes into energy – indirect recycling.

Refuse derived fuel (RDF) Fuel produced by shredding and dehydrating municipal solid waste such as shredded paper and plastics.

Sanitary Landfill American term for controlled landfill.

Shredder A mechanical device which tears or cuts material into small pieces. Used to reduce the size refuse, scrap metal, paper, card, plastic pieces, etc.

Stabilisation As applied to landfill, this term includes the degradation of organic matter to stable products, and the settlement of the fill to its rest level. The process can take more than 20 years to complete. The term also refers to the use of plants to prevent soil erosion from the surface of a landfill or spoil heap.

Vermin Used collectively to describe insects and small wild animals whose habitat is associated with filth, disease and decay.

Waste (European definition) Any substance or an object the holder discards, intends to discard or is required to discard [EU, 2006].

Waste (Thai definition) Refuse, garbage, filth, dirt, wastewater, polluted air, polluting substances or any other hazardous substances which are discharged, originated from point sources of pollution, including residues, sediments or remainders of such matters, either in the state of solid, liquid or gas [NEQA, 1992].

Waste management The collection, transport, processing, recycling or disposal and monitoring of waste materials.

CURRICULUM VITAE

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1999-2000: 'Aufbaustudium' Program in Biogeography, Department of
Biogeography, Faculty of Social and Environmental Science,
University of Saarland, Saarbruecken, Germany
2000-2003: Master of Science in Environmental Management, Faculty of
Environmental Management, Prince of Songkla University, Thailand

WORK EXPERIENCE

2000: Interpreter for Australian Master Students from University of
Queensland on their research 'Food Sanitary in Romdon' in HatYai, Thailand
Interpreter and Planning assistant of the Royal Danish Ministry of
Foreign Affair for a PhD research Project of Roskily University, Denmark
2000-2003: English teacher of ECC (English and Computer College) HatYai, Thailand
A teacher for a basic German Course of Inlingua, HatYai, Thailand
2005-2006: A co-ordinator and assistant researcher of a join Thai-Japan research
project in developed recycling system, funded by JICA (Japan
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SCHOLARSHIP

1999: DAAD scholarship, Aufbaustudium Program
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PUBLICATION

Pattaraporn Pimolthai. 1998. Tissue culture of Lily (*Lilium longiflorum*), Prince of Songkla University, Thailand

Pattaraporn Pimolthai. 2000. Effects of different land use patterns on the genetic variability of selected indicator-organisms. University of Saarland, Germany

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