Municipal solid waste treatment technologies the possibility to apply in developing countries, a case study in Vietnam

Le Thi Kim Oanh, Wim H. Rulkens, Joost C.L. van Buuren

***Abstract*— On the basis of the characteristics of technologies, including mass balances, technical, environmental, social and economic criteria an assessment was made to analysis the appropriate municipal solid waste (MSW) treatment technologies for developing countries, including aerobic composting, anaerobic digestion, incineration and sanitary landfill. The strengths and weaknesses of each technology in the condition of developing countries and also the detail data relation to cost and benefit, technical, social and environmental impacts have indicated. The research showed that the choice of suitable technology much depends on the condition of density cities of developing countries, among that: high amount and typical characteristic of MSW, tropical weather, lack of budget and infrastructure, lack of efficiency technologies and skilled worker, weak of management control and support system; and land scare and high requirement of electricity. Landfill is now still the best choice to dump MSW in developing countries due to its advance in cost and convenient. However, biological treatments will increase their ratio due to land scare and the requirement of compost in agriculture countries, especially in case of MSW separation at sources as the plan of many developing countries. Anaerobic digestion is not yet applied in large scale in developing countries. Recently, the decision makers are considering on this technology due to the need of electricity and its advantage when the moisture of MSW is high. Incineration is the most expensive technology among others. It is even more expensive when MSW in developing countries is low heat value and high moisture content.**

***Index Terms*— municipal solid waste, treatment technology, developing country.**

I. INTRODUCTION

Increasing population, booming economy, rapid urbanization and the rise in community living standards have greatly accelerated the MSW generation rate in developing countries (Minghua et al., 2009). Solid waste management is a challenge for the cities' authorities in developing countries mainly due to the increasing generation of waste, the burden posed on the municipal budget as a result of the high costs associated to its management, the lack of understanding over a diversity of factors that affect the different stages of waste management and linkages necessary to enable the entire handling system functioning (Lilliana Abarca Guerrero et al., 2013). In recent years, the required budget for MSW treatment in developing cities is rising quickly, especially where the availability of land for MSW treatment is limited and the environmental standards become stricter. Many technical and management measures may help to reduce the amount of MSW and protect the environment and public health. New technologies convert waste to valuable products resulting in a reduction of costs.

Le Thi Kim Oanh, Department of Environmental Technology and Management, Van Lang University, Ho Chi Minh City, Vietnam
Wim H. Rulkens, Department of Environmental Technology and Management, Van Lang University, Ho Chi Minh City, Vietnam
Joost C.L. van Buuren, Sub-department of Environmental Technology, Wageningen University, the Netherlands

Worldwide treatment technologies have been developed and are emerging that fit with this concept of resource management. Among these aerobic composting, anaerobic digestion, incineration and landfill technologies are most common, especially in developed countries. Besides, there are advanced technologies, such as gasification, pyrolysis, plasma... These technologies may have advantages in the processing of specific waste streams. However, they are costly, less suitable for wet MSW of the tropical rain countries, still in a developing phase and not clearly proven in practice in developing countries (Oanh 2012, Crowe et al. 2002). Therefore it is still not adopted in this paper as potentially appropriate technologies for developing countries in short time. The aim of this research is to review common technologies of aerobic composting, anaerobic digestion, incineration and landfill and selects among the various modifications of these technologies those that are appropriate to typically characteristic of MSW and tropical rain weather, as a case of cities in Asian developing countries. For this selection a set of criteria is applied. It has to be noted that technologies are defined and meant/considered here as complete treatment chains that include the mentioned main treatment step but also includes several pre-treatment and post treatment steps.

II. CRITERIA FOR APPROPRIATE MSW TREATMENT OPTIONS

Applying the methodology to select the criteria for appropriate drainage and sanitation system by Van Buuren (2010, p.47-69) and Zurbruegg and Tilley (2007), the criteria used for the selection of appropriate technologies for MSW treatment are subdivided into four groups: (1) technical efficiency, (2) environmental and health performance including also sustainability aspects, (3) social manageability and (4) economic affordability. These 4 groups of criteria are detailed in the next paragraphs.

2.1 Technologies should be technically efficient

Lack of knowledge of treatment technology by authorities is reported as one of the factors affecting the treatment activities in developing countries (Chung and Lo, 2008). And lack of relevant information that has to be given to the end users of the product. Sometimes also the wrong product is produced because of lack on insight in the market for the various possible products that can be obtained from the treatment process. Shekdar (2009) argues that many composting plants have been shut down, among others, due to inadequate monitoring of the quality of the compost being produced and incompatibility of plant design with the characteristics of the solid waste. Both factors are related to local available knowledge and appropriate infrastructure. Therefore, appropriate technologies should be capable of processing the MSW with the quality and quantity and the climatic conditions of the city under study. The MSW in tropical developing countries with its high content of biological organic matter and moisture is especially suitable for biological processes and the temperature makes aerobic composting and anaerobic digestion at mesophilic conditions attractive possibilities (Kim Oanh 2009).

Appropriate technologies should be robust, flexible and easily operable. Robustness could mean study, durable and resilient. Robust technologies need little repair and if necessary the maintenance is simple. Flexibility refers to the capacity to process a varying flow of wastes (Van Buuren 2010, p.50-52; Zurbruegg and Tilley 2007). It can be expected that in developing countries the amount and composition of the waste and also the required products from the waste treatment system will change rapidly and continuously. In that respect the treatment system should also be flexible.

2.2 Technologies should have a high environmental, including also sustainability aspects and health performance

Appropriate technologies should comply with environmental, sustainability aspect and public health requirements. They have to satisfy the local standards for discharge of pollutants into air and for noise, for discharge of treated wastewater into surface water or into the sewerage system. In general, the requirement for discharging in developing countries is less strict compared to developed countries. Therefore, most of recently applied technologies in developed countries are fit in the developing countries (Kim Oanh, 2012).

Appropriate technologies should make optimal use of resources. The performance can be expressed in indicators that reflect a low consumption of water, energy, land and chemicals and a high production of useful products such as soil conditioners, nutrients, biogas, electricity and utilizable heat (Zurbruegg and Tilley 2007; Van Buuren 2010, p.52-55). Land use of MSW treatment in particular is a critical issue in Asian cities. Therefore, there exists a strong preference for technologies that use little land, like incineration, anaerobic digestion and in-vessel composting.

2.3 Technologies should be manageable under the institutional conditions of Asian cities

The factors affecting negatively the environmental aspect of solid waste management in developing countries are the lack of environmental control system and evaluation of the real impacts (Matete and Trois, 2008; Asase et al., 2009). Different MSW treatment technologies will require different regulations and control mechanisms, especially based on the characteristic of MSW in developing countries, such as: high organic matter and moisture content, changing in composition of MSW and product'quality... These requirements should fit in the existing institutional infrastructure of the government. The technologies should be in agreement with the solid waste management planning, such as the program on solid waste separation at the source, the master plan on solid waste management systems, the strategy of solid waste management of the cities/countries and master plan on socio- economic development of the city.

It is suggests that technical factors influencing the system are related to lack of technical skill among personnel within municipalities and government authorities (Hazra and Goel, 2009) while skilless labor is available and cheap in developing countries. Therefore, application of high-tech options requires time and money for training and education and entails an increased risk of failure; consequently, there is a preference for technologies that are relatively simple with regard to construction, operation and maintenance, like aerated static pile composting and sanitary landfill.

Appropriate technologies should preferably apply equipment that can be replaced and repaired locally. Brand-new or second-hand spare parts are available for popular equipment such as engines and pumps. The equipment is imported from the regional market among developing countries at low prices but is not of high quality. Some technical equipment can be produced locally.

2.4 Technologies should be affordable to the cities

Mufeed Sharholy et al., (2007) concluded that the authorities are failed to manage the solid waste due to financial factors. The costs of the solid waste management are equal to the overall gross costs minus the overall financial benefits. The gross costs of MSW treatment depend on the type of technology applied and the requirement of environmental control. The financial benefits are to a high degree determined by the effective demand for end products on the local markets. The markets for compost (Bio-waste Reuse in South East Asia Project, 2006; Vietstar composting company, 2014[1]) and for recyclable waste such as plastic, paper, rubber... (Ha 2006, Recycling Fund in HCMC, 2014[2]) are big and active in developing cities but the quality of the its products are often low. Besides, low recycle process results in high polutions. New technologies should lead to a higher quality of the end products and reduce pollution. Such quality increase is expected to improve marketability but also leads to higher product prices. In addition, future government planning or policy may effects to this cost. In the case of Vietnam, since 2014, Waste-to-energy technologies are encouraged with the price (set up by the Goverment) of electricity produced from incineration technology is 10.05 US cent/Kwh and from landfill is 7.28 US cent /Kwh (Decision no. 31/2014/QĐ-TTg on 5/5/2014). While, the market price of electricity for industries is 6,8 US cent/KWh[3].

[1] Vietstar company survey data on 15/ 10/2014.
[2] Personal interview the Vice chair of Recycling Fund in HCMC on 15/5/2014.
[3] EVN HCM Power Company website on 2015: 1518 VNĐ/kWh.

III. THE TECHNOLOGIES TO CONVERT THE MSW IN DEVELOPING COUNTRIES

3.1 Aerobic composting technology

In general, there are 3 composting process, including windrow composting, aerated static pile composting and in-vessel composting (Tchobanoglous, 1993). Windrow composting technology has been applied long ago in developing countries like Vietnam, Thailand, Philipine, India…and recent decades the three aerobic compost process has applied in large scale. The composting technology is a feasible solution for MSW treatment in developing countries, since: Increasing of amount of MSW and the lack of land availability required a technology that replaces landfill (Kim Oanh, 2012, p.3); Adapted to the MSW management strategy of the developing countries; MSW in developing countries has a high fraction of organic material (Miezah Kodmo et al., 2015; Jun Dong et al., 2014, Kim Oanh, 2012), suitable for biological conversion; The stable mesophilic ambient temperature is favorable for composting; The potential agricultural demand for organic fertilizers and soil conditioners is huge and exceeds the actual supply by far (Tam et al., 2006); Composting is a flexible, relatively simple and inexpensive technology. The strengths and weaknesses of composting technologies applying in developing countries are summarized in table 1. The mass balance of MSW composting in HCMC, Vietnam is showed in figure 1.

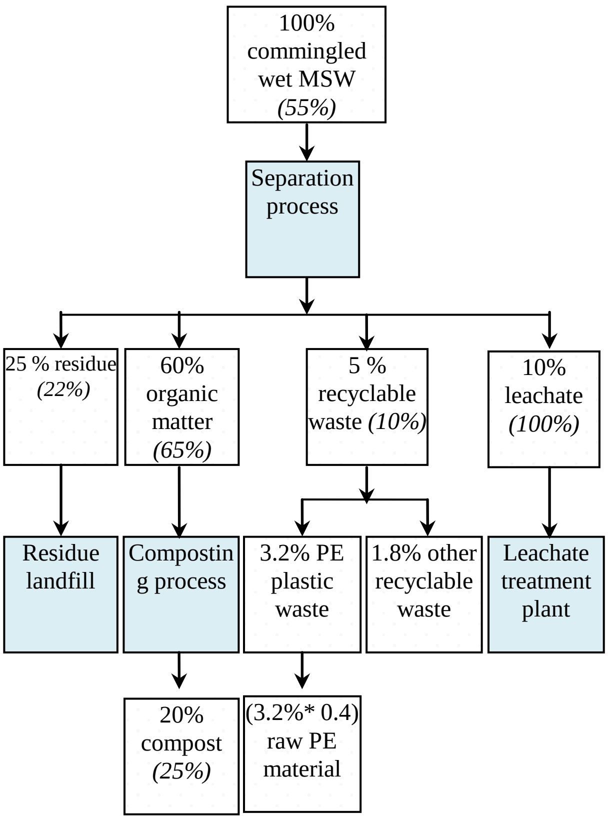

Figure 1 Mass balance of commingled MSW composting in HCMC, Vietnam.

Note: the percentages between brackets (in italics) indicate the moisture content. PE: PolyEthylene.
Source: Le Thi Kim Oanh (2012).

Table 1 Strengths and weaknesses of composting technology in developing countries.

Strengths	Weaknesses
- High percentage of compostable fraction (60% in wet weight of commingled MSW in Vietnam- CENTEMA, 2009; 68% in Ghana- Miezah Kodwo, 2015); - It can reduce the volume of compostable fraction by 20 - 50% and produce 0.2-0.25 ton compost/ton commingled MSW input (Tchobanoglous, 1993; Kim Oanh, 2009); - Simple technology and standard equipment; - Lower investment and operation costs compared to anaerobic digestion and incineration (Demes et al., 2003; Economolous, 2010); - High market for compost product; - Potential opportunities in co-composting of other waste streams, e.g.: manure, sewage sludge; - Requires less land as compared to sanitary landfills; - Local experiences and technologies are available in Vietnam; - Compost use represents recovery of C, N, P, etc. - High opportunity for collecting recyclable waste (resource sustainability); - Creates jobs for skilless people who separate MSW; - Low labor costs; - Increasing number of local construction firms with low priced equipment; - A high demand and a relatively high price for compost end product specially benefit from recyclable waste.	- High potential of odor, greenhouse gas and leachate production due to high compostable fraction and moisture and under the tropical weather; - Only converts the organic fraction of the waste stream and sensitive to toxic compounds, glass, plastic in commingled MSW; - High greenhouse gas emissions; - High land requirement compared to anaerobic digestion or incineration. - About 25% of total commingled MSW input residues has to be discharged to landfill (Kim Oanh, 2012). - Required a complex separation process to classify commingled MSW which may result in low quality of compost if the separation process is not in good performance and also result in high investment and operation cost. - The composting plant should be located indoor to protect the piles from heavy rain. - Increasing the environmental quality control in developing countries. These make the composting process in developing countries relatively expensive.

Land requirements for windrow, aerated static pile and in-vessel composting are about 10,000 - 20,000 (Tchobanoglous et al. 1993, p.695-696, Golder Associates 2009 [4]), 20,000 and 30,000 - 32,000 ton MSW/ha/year (Renkow, 1993), respectively. Electricity consumption for aerated static pile composting is 30-35 kWh/ton MSW (Hartmann and Ahring, 2006; Baldasano and Soriano, 2000; Economopoulos, 2010 and Fricke et al., 2005), while for in-vessel composting is about 55 kWh/ton.

Kim Oanh (2012) calculated the fixed, operation and treatment cost of aerated static pile composting plants for the capacity of 100,000- 500,000 tons wet commingled MSW/year in HCMC are 1.21- 3.30 million USD/year, 16.8-

[4] Adopted from http://www.epem.gr/waste-c-control/database/html/Composting-02.htm.

10.4 USD/ton and 28.9- 17USD/ton, respectively. These costs are equal to 30%, 50% and 31% to those of Europe (WRAP, 2009; Economopoulos, 2010). Kim Oanh (2012) also estimated the total income (financial benefits) from composting technology of 12.7- 13.7 USD/ton MSW input, including 6-7 USD from compost product, 5- 8 USD from selling raw PE material and 0.9 USD from other recyclable waste.

3.2. Anaerobic digestion technology

The number of anaerobic digestion plants has increased in developed countries due to the fact that the technology satisfies the requirements of solid waste treatment and produces biogas and compost (De Baere 2006; Joshua et al. 2008, Azeem Kalid 2011). Costs analysis of anaerobic digestion technology in Europe showed that anaerobic digestion of MSW for different scales is increasingly competitive with composting (De Mes et al. 2003). The survey by R-W-BECK (2004) on Linde-BRV, Kompogas and Valorga systems led to the conclusion that the investment costs declined over the past decade by continuously applying process improvements.

Anaerobic digestion of the digestable fraction of MSW has been applied mostly at small scale (0.5-10ton/day) in developing countries (Yvonne Vogeli, 2014), especially in India[5]. The biger size of anaerobic digestion plant has applied some places, such as the anaerobic digestion of MSW of Rarong' Municipality with capacity of 60ton/day. Unfortunately, this system was not well in operation due to technical problems (Chak Cherdsatirkul, 2012). However, given the high content of organic matter and moisture in the MSW, taking into account the high demand for electricity which can be produced via biogas from anaerobic digestion and considering the many limitations and problems of landfill and aerobic composting, anaerobic digestion technology should be considered an interesting technology in developing countries. Strengths and weaknesses of anaerobic digestion technology in developing countries are presented in Table 2.

Table 2 Strengths and weaknesses of anaerobic digestion technology in developing countries.

Strengths	Weaknesses
- The biogas production from biological fraction of MSW in Europe amounts to 80 – 200 m^3/ ton (de Mes, 2003) while in developing countries (in experimental scale) amounts to 59- 250 m^3/ ton (Kim Oanh, 2012; Yvonne Vogeli, 2014). - Digested substrate can be converted to compost with about 25% in wet weight of commingled MSW in HCMC (Kim Oanh, 2012); - Potential to treat the wet fraction of MSW that is less amenable to incineration and aerobic composting; - Lower land requirement than landfills; - Less greenhouse gas effect than composting; - Compost use represents recovery of C, N, P, etc. - Opportunity for collecting recyclable waste (resource sustainability) from commingled MSW. - Commingled MSW has to be separated to get the compostable fraction. Therefore, it creates jobs for skilless people. However, it is also a crucial factor about health care.	- High investment and comes with high operation and maintenance costs compared to landfill and composting (Demes et al., 2003; Economolous, 2010); - More complex technique compared to composting; - The digestate of anaerobic digestion is less effective for pathogen removal and requires a composting process. - Lack of application in full scale in developing countries to prove its technical efficiency and benefits. - Biogas-based electricity not competitive in developing countries where electricity is subsidy and no/less supported for green electricity. - May get less biogas product and low quality of compost due to impurities in input (commingled MSW). - About 25% of total commingled MSW input is discharged to landfill as residue. - lack of information about and legal obstacles to the acceptance of certain (co-) digestion products in agriculture.

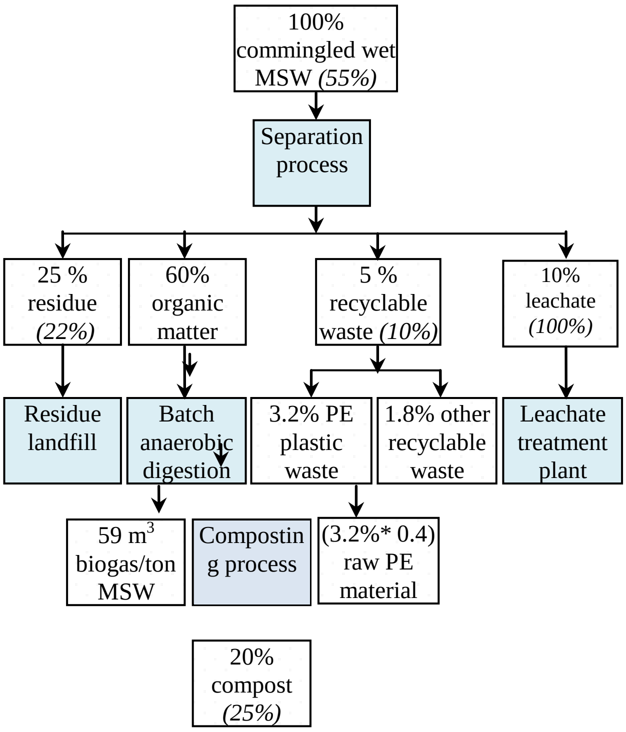

Figure 2 Mass balance of commingled MSW anaerobic digestion in HCMC, Vietnam.
Note: the percentages between brackets (in italics) indicate the moisture content.
Source: Based on the data of Kim Oanh (2012).

Among the anaerobic technologies applied, the dry one-stage and semi-continuous system technology is mostly used for MSW (Vandevivere et al. 2002; De Mes et al. 2003; Hartmann and Ahring 2006). The treatment cost of this technology in Europe are in the range of 80 - 123 USD/ton wet digestable fraction of MSW respectively for plants with a capacity of 30,000 - 500,000 tons wet digestable fraction of MSW/year (De Mes et al. 2003; Clarke, 2000; Economopoulos, 2010). The dry digestion needs about 78 liters of water and about 50 - 55 kWh to process 1 ton of wet digestable fraction of MSW in European countries (European

[5] http://www.vivamgroup.co.in/msw_biogas.html

Commission, 2006). In case of developing countries, the moistrure content in MSW is high; it may not need to add water.

Kim Oanh estimated the treatment cost about 29-50.4USD/ton and 36.3-21.1 USD/ton commingled MSW input for the continuous and bath technologies with the plant'capacity of 100.000-500.000 ton/day, respectively. She also estimated the income from these continuous and bath technologies. That was about 19.3- 29.9 USD/ton and 17.6-20.7 USD/ton, respectively.

3.3. Incineration technology

The aims of incineration of MSW are reduction of the waste volume and the emissions from final waste disposal and recovery of energy from the combustion gases. Incineration technology is increasing significantly its role in developed countries; while it is still in the initial phase of developing countries. Below the most significant strengths and weaknesses of the incineration technology in developing countries is summarized in table 3.

Table 3 Strengths and weaknesses of incineration technology in developing countries.

Strengths	Weaknesses
- Reduction of the volume of MSW is up to 80 - 90% and reduction of weight up to 70 - 75% (DEFRA, 2013, p.15) - The residence time is very short (maximal one hour) which contributes to a small footprint; - Destroying all toxic organic material and pathogens in an effective manner; - The emissions can be controlled effectively; Therefore, the system can be located inside or nearby the discharge sources, which can reduce the transportation costs; - Phosphate, Al, Fe can be recovered from incineration ashes; - Incineration technology gains high carbon credits in CDM/JCM projects than landfill. (Kaplan et al., 2009) - Incineration has a high potential for energy production.	- Investment and treatment costs are high; - Requires highly skilled staff; - The flue gas treatment needs advanced technology and highly skilled management to avoid pollution of the environment; - Incineration is less suitable for MSW with a low heat value and is sensitive to a high moisture content in the waste as a case of tropical developing countries; - High volume of ash (about 25% (w) of total commingled MSW input). Land is needed for the disposal of the fly ash and bottom ash, if the ash is not recycled; - No experience at large-scale. - Energy yield is very low due to the high moisture content of the MSW and low heat value. - No possibility to collect recyclable waste such as plastic, paper, rubber...

A variety of incinerator types have been used for the combustion of waste. The grate system is one of the most crucial components of a mass burn furnace (Kreith 2002, P.13). There are two main different grate types: the movable grate and the rotary grate. World Bank (1999) showed that the mass burning principle with a movable grate is a feasible and well-proven technology. In European countries, mass burn incinerators usually range in capacity from 45 to 900 tons waste/day (Europen Environment Agency 2009)[6]. A typical plant would require about 45 tons of MSW to generate 1 megawatt (MW) of electricity of power for 24 hours (533 kWh/ton) (Cheremisinoff 2003, p.42). According to Dijkgraaf and Vollebergh (2004), about 580 kWh of electricity, 299 kWh of thermal heat, 1.6 kg aluminium and 34 kg iron were produced per ton of MSW in the Netherland with an incinerator with a capacity of 684,000 tons/year. In the research of Kaplan (2009) an electricity production from incineration in United State of about 470 - 930 kWh/ton MSW was reported. Economopoulos (2010) found that incineration plants of MSW in Europe produced 640 kWh/ton MSW and consumed about 175.4 kWh/ton MSW. While, in Taiwan, 219- 592 kWh/ton of electricity is produced from incineration plants with lower heat value of 1,350-2,500kcal/kg MSW (W.T.Tsai, et al. 2006). In case of Singapore, it reported that electricity production of 250-300 kWh/ton commingled MSW[7]. Land use of incineration technology is 15,000 - 63,000 tons MSW/ha/year (Economopoulos, 2010).

In countries where the waste to be combusted has a high moisture content (> 40%) and the lower heat value is less than about 6 MJ/kg the regular incineration technologies will not suffice. To maintain the combustion process a certain amount of additional fuel has to be added, the grate design has to be adapted and/or an external drier has to be used to reduce the moisture content before the MSW is fed to the combustion chamber. Use of a dryer can improve the net energy efficiency, however requires much higher investments.

Similar to other technologies, treatment costs of incineration decrease with increasing scale. Therefore, World Bank (1999) has proposed that individual incineration units should have capacities of at least 240 tons/day while in the case of Taiwan the capacity is at least 300tons/day (W.T.Tsai, et al, 2006). Rabl et al. (2008) and Perkoulidis et al. (2010) found that the treatment cost of incinerator is of 69.7 and 66.6 USD/ton at capacities of 300,000 and 500,000 ton MSW/year in Euro.

Recently, the possibility to apply incineration technology in developing countries is increasing due to: (1) The pressing need of an efficient technology for volume reduction of the strongly growing amount of MSW; (2) The increasing scarcity of land for MSW treatment; (3) Incineration may produce electricity and heat; (4) If incineration projects are registered for CDM or JCM, a high number of carbon credits may be earned; and (5) The encourage policy for Waste-to-energy technology. To promote waste-to-energy, in Vietnam the government set up the price of electricity from incineration and landfill are 10.05 and 7.28 US cent/Kwh, respectively (Dec.no. 31/2014/QĐ-TTg); while in Thailand, the adder of Bt3.50/kWh for power produced from incineration and gasification, the adder of Bt2.50/kWh for power produced from gas at landfill waste and biogas from

[6] http://www.eea.europa.eu/publications/EMEPCORINAIR/group09.pdf
[7] http://www.unep.or.jp/ietc/ESTdir/Pub/MSW/RO/Asia/Topic_d.asp

waste fermentation are introduced[8]. A mass balance for incineration of MSW in HCMC is presented in figure 3.

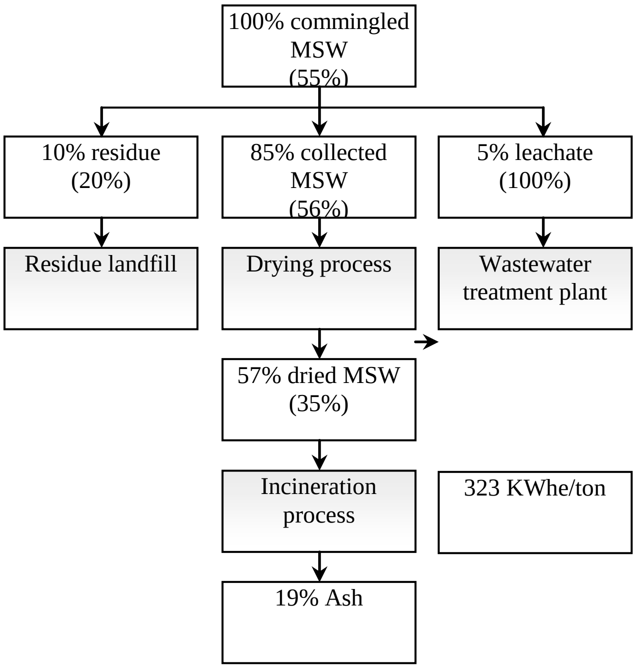

Figure 3 Mass balance of an incinerator in Ho Chi Minh City.
Note: the percentages between brackets (in intalics) indicate the moisture content
Source: Le Thi Kim Oanh, 2012.

Kim Oanh (2012) estimated the treatment cost of incineration technology in HCMC with capacity of 200.000-500.000ton/year were 56.8-44 USD/ton MSW. Take into account of the electricity price via the Decision n_o. 31/2014/QĐ-TTg and based on data of Kim Oanh (2012, p.123), the income of incineration (from electricity and heavy metals recovery) in HCMC is estimated about 11.56-53.27USD/ton MSW.

3.4. Sanitary landfill technology

Although landfill is almost no use in many developed countries like Singapore, Switzerland, Sweden, Denmark, Netherlands…It is still a common method of MSW disposal in the rest of the World. Strengths and weaknesses of sanitary landfill technology in developing countries is presented in table 4.

Table 4 Strengths and weaknesses of sanitary landfill technology in developing countries.

Strengths	Weaknesses
- Landfill is a flexible and relatively simple technology that can be applied for all types of solid waste; - Depending on legal requirements and local conditions landfill may be a good option in terms of costs and required operation skills; - Landfill produces methane (53m^3 CH_4/ton MSW in Malaysia) (Nuruljannah, 2015) - It is common technology for MSW treatment developed through upgrading of the traditional open dumping method. Therefore, solid waste decision makers usually accept landfill rather easily. - Local experiences and technology available. - Capacity of landfill can be increased step by step which adapt to the lack of budget of developing countries.	- Landfill technology requires much land compared to other technologies (180,000 ton/ha dumping cell) and it occupies the land during a long period (about 20 years) (DONRE, 2009); - MSW content high percentage of biological waste (>50%) and moisture (55-60%) (Kim Oanh, 2012; Nuruljannah, 2015), under tropical weather will discharge more odor, greenhouse gases and leachate. - A landfill site remains a source of contamination until it is recovered; - The convenience of landfill tends to discourage the development of innovative more sustainable waste management options. - No possibility to collect recyclable waste and no resource recovery (N, P).

According to O'Leary and Tchobanoglous (2002, p.14.15), the theoretical amount of biogas that would be expected under optimum conditions from rapidly and slowly biodegradable organic wastes in a landfill varies from 750 to 936 and 874 to 999 m^3/ton of dry biodegradable organic solids converted, respectively. However, in practice, based on the findings of Veolia (2010)[9], from every ton of MSW dumped at a sanitary landfill, 142 m^3 of biogas is produced during the operation time of 25 years. Within the first 10 years the recovered volume of biogas is 109 m^3/ton (77% of the total biogas production).

Bioreactor landfill is an upgraded sanitary landfill where it enhances the microbiological conversion process. The potential benefits of anaerobic bioreactor landfills are: (1) Increase of the energy recovery potential due to fast digestion leading to an increased volume of biogas collected in a shorter period of collection and reduce of potential pollution (Fredrick, 2013). According to data of Veolia (2010) the volume of recovered biogas is about 142 - 217 m^3/ton MSW during the first two years after disposal; over the first five years the biogas production is in the range of 185 - 282 m^3/ton; (2) Rapid settlement results in an increased air space recovery which is up to 30% of total volume of the bioreactor landfill within 2 years (Townsend et al. 2008). It results in higher land use efficiency compared to the traditional landfill (5 - 10 years vs. 25 - 50 years) (ITRC 2006); (3) Leachate can be treated inside the bioreactor landfill. Therefore, the costs of leachate treatment can be reduced. This is important as the costs of leachate treatment in Vietnam account for 30% of the total treatment costs of landfills (DONRE HCMC 2009); (4) Reduction post-closure maintenance and risk due to rapid stabilization. It is estimated that the reduction amounts to about 40 - 50% of total costs of post-closure monitoring based on the post-closure time reduction (Yazdani et al. 2007); (5) Landfills are cited as an important source of greenhouse gases. However, anaerobic bioreactor landfills have a more efficient biogas collection system, so that less greenhouse gas is discharged (Salukele, 2013).

Kim Oanh (2012, p.128) calculated based on the actual data of Phuoc Hiep landfill in HCMC, VN showed that the treatment cost of landfill with capacity of 100,000-1,100,000

[8] http://weben.dede.go.th/webmax/content/thailand-needs-promote-energy-waste. The ratio of 3,500Bt~100USD.

ton/day were 28-20 USD/ton; while, the benefit from electricity were 14.07-20.1 USD/ton. Each hectare of sanitary landfill cells can hold about 180,000 tons of MSW.

IV. CONCLUSIONS

Several technologies are available to treat MSW in developing countries. The main ones are aerobic composting, anaerobic digestion, incineration and landfill, that all have their strengths and weaknesses to apply in developing countries. The choice of one or more proper technologies in a situation under study depends to a high extent on local conditions. Taking into account the condition density cities of of developing countries, it is included: (1) the increasing of amount of MSW, (2) the characteristic of MSW: commingled waste (not separation at sources), high biological organic fraction, high moisture content and low heat value; (3) the lack of budget for MSW treatment; (4) the lack of local efficiency technologies; and (5) the lack skilled person and management control on the new technologies. Looking into the near future, landfill is still a good option for developing countries due to it adapt to the urgent need to solve a high amount of commingled MSW. However, landfill will become less and less when land scare is increasing in density cities. Composting technology has existed long ago and recently years it is applied in large scale which adapt to the big market of compost in agriculture countries of most of developing countries. Recently years, the requirement of electricity and the back draw of compost technology that is a strong power to consider of anaerobic technology in developing countries, however, it needs time to prove its application. Incineration technology is expensive and not suitable for wet and low heat value of MSW in developing countries. It will be applied when MSW is separation at sources and/or the technology adapt to high moisture of MSW.

In order to further assess whether the technologies are suitable for a certain developing country, it requires further information under local condition, includes: (1) Costs analysis, such as: fixed and operation costs, product quality-quantity and prices, market requirements; (2) Costs comparison among MSW treatment technologies; (3) Environmental aspects, such as: electricity use, land use, discharge management and control, product quality and monitoring; (4) Future environmental regulations, example: if the costs of prevention the environmental damage or the promotion regulation of waste-to-energy are included, the preference for incineration will increase, (5) Social aspects such as compatibility with local regulations and the availability of skilled personnel.

REFERENCES

[1]Asase, M., Yanful, E.K., Mensah, M., Stanford, J., Amponsah, S., 2009. Comparison of MSW management systems in Canada and Ghana: a case study of the cities of London, Ontario, and Kumasi, Ghana. Journal of Waste Management 29, 2779–2786.

[2]Azeem Khalid, Muhammad Arshad, Mazammil Anjum, Tarig Mahmood, Lorna Dawson. 2013. The anaerobic digestion of solid organic waste. Journal of Waste Management, Volume 31, Issue 8, 1737- 1744.

[3]Baldasano, J.M., and C. Soriano. 2000. Emission of greenhouse gases from anaerobic digestion processes: comparison with other MSW treatments. *Water Science and Technology* 41 (3):8.

[4]CENTEMA. 2009. The report on data collection on solid waste management in Ho Chi Minh City, Viet Nam. (Chuong trinh co so du lieu quan ly chat thai ran tren dia ban thanh pho Ho Chi Minh nam 2009). In *City report*. Ho Chi Minh City, Viet Nam.

[5]Chak Cherdsatirkul, 2012. Generation and disposition of MSW management in Thailand. Department of Earth and Environmental Engineering- Columbia University.

[6]Cheremisinoff, N.P. 2003. *Handbook of solid waste management and waste minimization technologies* USA: Elsevier Science

[7]Chung, S., Lo, C., 2008. Local waste management constraints and waste administrators in China. Journal of Waste Management 28, 272-281.

[8]Crowe, M., K. Nolan, C. Collins, G. Carty, B. Donlon, and M. Kristoffersen. 2002. Biodegradable municipal waste management in Europe (Part 3: Technology and market issues). In edited by D. Tsotsos. European Environment Agency.

[9]De Baere. 2006. Will anaerobic digestion of solid waste survive in the future? *Water Science and Technology* 53 (8):8.

[10] De Mes, T.Z.D. , A.J.M. Stams, J.H. Reith, and G. Zeeman. 2003. *Methane production by anaerobic digestion of wastewater and solid wastes, Bio-methane and Bio-hydrogen. Status and perspectives of biological methane and hydrogen production.*: Dutch Biological Hydrogen Foundation.

[11] DEFRA (Department for Environment Food & Rural Affairs. 2013. Incineration of Municipal Solid Waste. United Kingdom.

[12] Dijkgraaf, E. , and H.L.J. Vollebergh. 2004. Burn or Bury? A social cost comparison of final waste disposal methods. *Ecological Economics* 50 (3-4):233-247.

[13] DONRE HCMC. 2009. The report on socialization of the SWM system, HCMC. (In Vietnamese: Bao cao ve tinh hinh xa hoi hoa he thong quan ly chat thai ran thanh pho Ho Chi Minh). In *City report*.

[14] Economopoulos, A. P. 2010. Technoeconomic aspects of alternative MSWs treatment methods. *Waste Management* 30:707-715.

[15] Europen Environment Agency. 2011. *Incineration of Domestic or Municipal Wastes (content list group 9)* [cited 20/11/2011].

[16] Fredrick Salukele. 2013. Bioreactor systems for municipal solid waste treatment in East Africa. PhD thesis, Wageningen University, the Netherlands.

[17] Fricke, K., H. Santen, and R. Wallmann. 2005. Comparison of Selected Aerobic and Anaerobic Procedures for MSW Treatment. *Waste Management* 25:799-810.

[18] Giac Tam, P. T., D. H. Xo, J.C.L. Van Buuren, L. T. K. Oanh, N. K. Thanh, and T. T. T. Trang. 2006. Towards the reuse of municipal biowaste in Vietnam - a case study about Ho Chi Minh City 2006. In *Biowaste reuse in southeast asian cities - Asia pro-eco program*, edited by T. T. M. Dieu, J. C. L. Van Buuren and T. T. Linh. Ho Chi Minh City: CENTEMA.

[19] Ha, H. T. 2006. The research on setting up the Recycling Fund to support the recycling activities in HCMC (Nghiên cứu xây dựng mô hình tổ chức hoạt động quỹ tái chế chất thải ở thành phố Hồ Chí Minh). In *City report* DONRE of Ho Chi Minh City.

[20] Hartmann, H., and B.K. Ahring. 2006. Strategies for the anaerobic digestion of the organic fraction of MSW: an overview. *Water Science and Technology* 53 (8):16.

[21] Hazra, T., Goel, S., 2009. Solid waste management in Kolkata, India: practices and challenges. Journal of Waste Management 29, 470–478.

[22] ITRC, Alternative Landfill Technologies Team. 2006. Characterization, Design, Construction and Monitoring of Bioreactor Landfills. Columbia: Interstate Technology & Regulatory Council.

[23] Joshua, R. , Z. Ruihong, M. J Bryan, and B. W. Robert. 2008. Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste. edited by C. I. W. M. Board: California Environmental Protection Agency.

[24] JunDong, Yong Chi, Daoan Zou, Chao Fu, Qunxing Huang, Mingjiang Ni. 2014. Comparison of municipal solid waste treatment technologies from a life cycle perspective in China. Waste Management & Research, Vol.32, no.1, 13-23.

[25] Kaplan, P. O., J. Decarolis, and S. Thorneloe. 2009. Is it better to burn or bury waste for clean electricity generation? *Environmental Science and Technology* 43:7.

[26] Kim Oanh, L.T. 2009. Renewable energy from municipal biowaste and pig manure. In Vietnamese: San xuat nang luong tu chat thai sinh hoat huu co va phan heo. In *City report*. Ho Chi Minh City: DOSTE of Ho Chi Minh City.

[27] Kreith, F. 2002. Waste-to-Energy combustion. In handbook of solid waste management, edited by G. Tchnbanoglous and F.Kreith. New York: McGrawHill.

[28] Le Thi Kim Oanh 2012. SURMAT: decision support tool to select MSW treatment technologies. Case study in Ho Chi Minh City, Vietnam. PhD thesis, Wageningen University, Wageningen, NL (2012). ISBN 978-94-6173-439-6.

[29] Lilliana Abarca Guerrero, Ger Maas, William Hogland. 2013. Solid waste management challenges for cities in developing countries. Journal of Waste Management 33, 220-232
[30] Matete, N., Trois, C., 2008. Towards zero waste in emerging countries – A South African experience. Journal of Waste Management 28, 1480–1492.
[31] Miezah K, Obiri-Danso K, Kadar Z, Fei-Baffoe B, Mensah MY, 2015. Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. Journal of Waste Management 46 (2015) 15-27.
[32] Minghua, Z., Xiumin, F., Rovetta, A., Qichang, H., Vicentini, F., Bingkai, L., Giusti, A., Yi, L., 2009. MSW management in Pudong New Area, China. Journal of Waste Management 29, 1227–1233.
[33] Mufeed Sharholy, Kafeel Ahmad, R.C.Vaishya, R.D. Gupta, 2007. Municipal solid waste characteristics and management in Allahabad, India. Waste Management 27(2007) 490-496.
[34] Nuruljannah Khairuddin, Lafifah Abd Manaf, Mohd Ali Hassan, Normala Halimoon, Wan Azlina Wan Ab Karim. 2015. Biogas harvesting from organic fraction of municipal solid waste as a renewable energy resource in Malasia: A review. Pol.J.Environ.Stu.Vol.24, No.4(2015), 1477-1490.
[35] O'Leary, Ph. R., and G. Tchobanoglous. 2002. Landfilling. In *Handbook of Solid Waste Management*, edited by G. Tchobanoglous and F. Kreith. New York: McGrawHill.
[36] Perkoulidis, G. , A. Papageorgiou, A. Karagiannidis, and S. Kalogirou. 2010. Integrated assessment of a new Waste-to-Energy facility in Central Greece in the context of regional perspectives. *Waste Management* 30:12.
[37] Rabl, A., J.V. Spadaro, and A. Zoughaib. 2008. Environmental impacts and cost of solid waste: a comparison of landfill and incineration. *Waste Management & Research* 26:16.
[38] Renkow, M., C. Safley, and J. Chaffin. 1993. A cost analysis of municipal yard waste composting. In North Carolina, USA: North Carolina State University.
[39] R-W-BECK. 2004. Anaerobic digestion feasibility study, final report. Bluestem Solid Waste Agency and IOWA department of Natural resources.
[40] Salukele, F.M., 2013. Innovative landfill bioreactor systems for MSW treatment in East Africa aimed at optimal energy recovery and minimal greenhouse gas emissions. PhD thesis, Wageningen University, Wageningen, NL (2013).
[41] Shekdar, A., 2009. Sustainable solid waste management: an integrated approach for Asian countries. Journal of Waste Management 29, 1438–1448.
[42] Tchobanoglous, G., H. Theisen, and S. A.Vigil. 1993. Integrated Solid Waste Management- Engineering principles and management issues. *McGraw-Hill International Editions.* Civil Engineering Series.
[43] Ten Brummeler, E. 2000. Full scale experience with the BIOCEL process. *Water Science and Technology* 14 (3):6.
[44] Townsend, T.G., D. Kumar, and J.H. Ko. 2008. Bioreactor Landfill Operation A Guide for Development, Implementation and Monitoring. Department of Environmental Engineering Sciences, University of Florida, US.
[45] W.T.Tsai, Y.H.Chou 2006. An overview of renewable energy utilization from MSW incineration in Taiwan. Journal of Renewable and sustainable energy reviews, 10 (2006) 491-502.
[46] Van Buuren, J.C.L. 2010. Sanitation Choice Involving Stakeholders, Sub-department Environmental Technology, Wageningen University, Wageningen University and Research Center, the Netherlands.
[47] Vandevivere, P. L., L. De Baere, and W. Verstraete. 2002. Types of anaerobic digesters for solid waste, in Biomethanization of the Organic Fraction of MSW. edited by J. Mata-Alvarez. Barcelona.
[48] Veolia. 2010. *The Bouqueval/Plessis- Gassot landfill*. Veolia environment 2010 [cited 29/9 2010].
[49] William Clark, 2000. Cost-benefit analysis of introducing technology to rapidly degrade municipal solid waste. Journal of Waste Management & Research, vol. 18, issue 6, 510-524.
[50] World Bank. 1999. Decision makers' Guide to MSW Incineration. Washington D.C. USA: The International Bank for Reconstruction and Development.
[51] WRAP. 2009. Comparing the cost of alternative waste treatment options. In *WRAP Gate Fees Report*.
[52] Yazdani, R., J. Kieffer, and K. Sananikone Yazdani. 2007. Controlled Bioreactor Landfill Program at the Yolo County Central Landfill, US. Paper read at Methane market partnership Expo., at Beijing, China.
[53] Yvonne Vogeli et al., 2014. Anaerobic Digestion of Biowaste in Developing countries- Practice information and case studies. Swiss Federal Institute of Aquatic Science and Technology, Dubendory, Switzerland.
[54] Zurbruegg, C., and E. Tilley. 2007. Assessment of Sanitation Systems and Technologies (Workpackage 3). In *Evaluation of Existing Low-cost Conventional as well as Innovative Sanitation System and Technologies*. NETSSAF, Deliverable 22 & 33. Project number 037099: EAWAG.