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Review Article

A REVIEW STUDY ON MUNICIPAL SOLID WASTE MANAGEMENT AND WASTE TO ENERGY TECHNOLOGIES

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ABSTRACT

Primarily used methods for disposal of Municipal Solid Waste (MSW) are open dumping and landfill in Thailand that have detrimental impacts on environment in the form of air pollution, water and soil contamination, and climate changes. The increasing amount of MSW from municipalities has emerged as a huge environmental menace for Thailand because of fast growing urbanization and industrialization. Hence, an eco-friendly and effective solution is the dire need to restore the environmental essence for a tropical country like Thailand. This paper presents a brief review on current waste treatment technologies which are being using for Municipal Solid Waste Management (MSWM) in the world and Thailand. Additionally, current studies on MSWM along with the implementation of gasification technology in Municipality solid WTE power plant in Hat Yai are discussed. In last, some concluding remarks and suggestions are proposed for MSWM and WTE technologies improvements in future.

INTRODUCTION

Nearly 1.3 billion tons of Municipal Solid Waste (MSW) is produced annually and is predicted to double up to 2.2 billion tons by 2025 globally. Municipal solid waste management (MSWM) is a complicated process and involves collaborative decision making on selecting waste collection routes, waste transfer stations as well as waste treatment facilities and strategies from different available options. The selection of a waste treatment strategy is one of the major debated issues in the literature and is the core of MSWM. Waste treatment facilities and strategies often consist of landfilling and Waste to Energy (WTE) technologies. Sustainability refers to the assessment of environmental, economic, and social impacts of available waste treatment options in the context of MSWM (Soltani, et al., 2016). To achieve the goals of sustainable waste management requires reducing waste generation, re-using and recycling waste materials, and recovering energy to ultimately preserve resources for the future. Recovering energy from disposed waste can generate energy for municipalities, substitution of fossil fuel to industries, and can reduce Greenhouse Gases (GHG) and other toxic air pollutants. WTE technologies in further details with advantages and disadvantages are given in Table 1.

Currently, developing countries have less available energy for consumption as compare to energy demand. While in present situation approximately 84% demand is fulfilled through fossil fuels worldwide. Due to high utilization and depletion of fossil fuel resources like coal, oil and natural gas, alternative energy sources such as WTE technologies are the best approach in diminishing the energy crisis in future (Ouda, et al., 2016). WTE conversion facilities require less land as compare to landfill dumping sites having same number of wastes. Therefore, WTE technologies are the efficient methods of managing waste by generating energy in an eco-friendly and economically viable way. Although various waste conversion processes are available, however the most commonly used WTE technologies for MSW treatment along with their types and products are shown in Fig. 1.

This paper presents a detail review on existing WTE techniques which are used for municipal solid waste treatment across the world as well as in Thailand. Besides, recent studies on MSWM as well as the implementation of gasification technology in municipality solid WTE power plant in Hat Yai are discussed. In last, some concluding remarks and suggestions are proposed for prospective improvements in MSWM and WTE technologies.

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Table 1. WTE technologies with advantages and disadvantages.

Technology	Advantages	Disadvantages
Thermal treatment incineration	-More suitable for MSW having high calorific value -Thermal energy for electricity production or direct heating -Less odor and relatively noiseless -Low land requirement -Minimum transportation costs, by constructing within city surroundings -Hygienic	- Least suitable for MSW containing more moisture content and low calorific value. - Ash, particulate emissions, NOx, Sox, chlorinated compounds, ranging from hydrochloric acid to dioxins contain toxic metal concentration - Skilled employees required - Capital cost, operational and maintenance costs are high - Efficiency as a whole is low for small power stations
Pyrolysis/ gasification	-Production of fuel gas/oil, which can be used for various purposes -Control of pollution superior as compared to incineration	- Total energy recovery may suffer in waste due to high moisture - High viscosity of pyrolysis oil may be problematic for its burning and transportation
Biochemical conversion	-Energy recovery with production of high-quality soil conditioner -No power requirement for turning of waste pile and sieving -Enclosed system enables trapping the gas produced for use -Controls GHG emissions -Free from rodent, bad odor and fly menace, social resistance and visible pollution -Less land area is required for compact design -Net positive environmental gains -Can be done in small scale	-Unsuitable for wastes containing less organic matter -To improve digestion efficiency waste segregation is required
Landfilling	-Economical -Gas generated can be used for electricity generation or direct heating -No skilled employees required -Natural resources are returned to the soil and recycled -Can convert marshy lands to useful lands	-Surface runoff causes pollution during rainfall -Leachate pollutes soil and groundwater table -Yields only 30% to 40% of the total gas produced -Large land area required -Significant transportation costs -Cost of pre-treatment to upgrade the gas to pipe line quality and leachate treatment may be significant -Spontaneous explosion due to methane gas build up

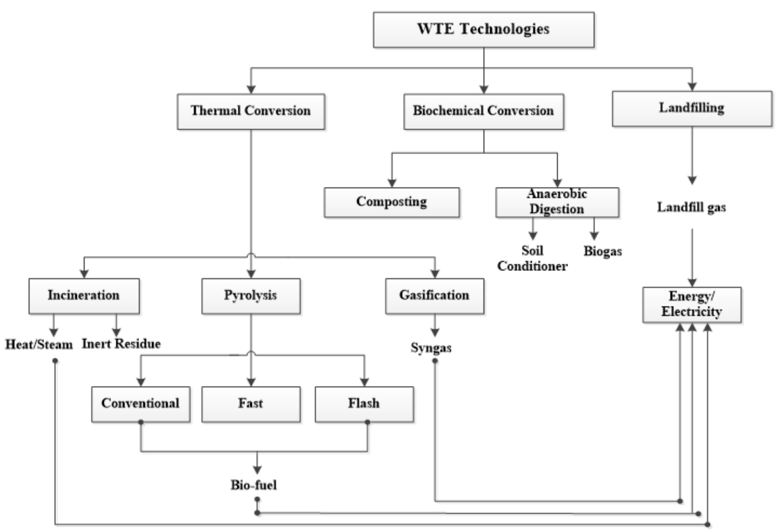

Fig. 1 Municipal solid waste treatment techniques and their products.

LITERATURE REVIEW

Recent Studies on Municipal Solid Waste Management

WTE power plants are operating from several years but current technology used in MSWM still facing many challenges in the world and is needed to be handled properly. Apart from this, many studies were conducted to reduce the amount of MSW as well as increasing the amount of generated energy by improving current WTE technologies. MSWM is pivotal to manage current WTE power plants in an eco-friendly and efficient way. Many investigations are performed on MSWM for local areas which covered MSWM and strategies of current techniques in local areas, thus, presenting the current description and giving further suggestions for modifications.

Udomsri et al. evaluated the potential of MSW incineration in Thailand to mitigate climate change and sustainable direction for development of biomass-based electricity generation. They inaugurated that the environmental impacts related to waste disposal could be reduce by MSW incineration, whereas it could expand biomass-based energy production positively (Udomsri, et al., 2011).

Akinci et al. studied waste disposal in Izmir, Kula, and Usak in Aegean region (Turkey) and presented a perspective planning. They analyzed methane production from green wastes through the biodegradation in Izmir and composting technique for Kula and Uşak (Akinci, et al., 2012).

Phillips and Mondal studied MSW disposal in India and presented a mathematical framework of sustainability options. They found that gasification technique had the potential for MSW treatment as a sustainable option because of their overall favourable impacts for the local people and environment (Phillips, et al., 2014).

Hossain et al. investigated MSW and their different types in Bangladesh. They asserted that incineration technology played an important role by reducing space for further landfills and performed an important role for production of energy. Although, low heating value and moisture content were identified as deficit for MSW incineration to generate energy. Muhammad et al. studied the feasibility of MSW for production of energy and current waste management methods in Pakistan. They examined that waste generated is openly burned in the atmosphere or either dumped directly in low lying areas because of improper engineered way of disposal. On contrary, solid waste produced in Pakistan has high potential to generate energy up to 265 million m3/year from thermo-chemical and 50.35 million m3/year from bio-chemical techniques (Hossain, et al., 2014).

Xiaoping et al. proposed planning for a carbon-constrained MSWM system on the basis of hybrid approach in Qingdao City, China. Muhammad et al. developed a framework applied to a case study in Abu Dhabi Emirate for seeking the optimal processing routes to handle and process MSW into energy and value-added products. They found from optimization results that an integrated pathway can provide potential economic benefits through recycling the recyclable components of MSW along with the production of bioethanol from the rest of the waste via gasification followed by catalytic transformation (Jia, et al., 2018; Hossain, et al., 2014).

Sara et al. discussed modern techniques followed in UK waste management system, excluding mass-burn incineration and landfilling. They compared three dual-stage advanced WTE technologies (gasification and plasma gas cleaning, fast pyrolysis and combustion and gasification with syngas combustion) with those related to existing MSW treatment practices (landfilling and incineration) with electricity production on the basis of environmental impacts. They noticed that the dual-stage gasification and plasma technique on environmental performance is significantly better than the existing waste treatment practices and comparatively better than a contemporary incineration plant, demonstrated by a plant under commissioning in Lincolnshire in the UK (Evangelisti, et al., 2015). Neha et al. reviewed the present status of solid waste management in India. They stated that growing population, urbanization and industrialization has increased MSW generation rate in Indian cities and towns which is a major environmental issue for MSWM (Gupta, et al., 2015). Lee et al. reviewed a case study of Hong Kong related to MSWM. They designed a mathematical model for MSWM according to Asian scenario. They highlighted that development of mathematical model is an urgent need which can be used for saving cost and selection of an appropriate choices by providing useful information for decision-makers (Lee, et al., 2016).

Fernández-González et al. discussed the different aspects (economic, environmental and territorial) of MSW to WTE in southern Spain. They compared anaerobic digestion, the production of Solid Recovered Fuel (SRF) and gasification with the present Biological Mechanical Treatment (BMT) with elimination of the reject in landfill, and incineration with energy recovery. They found that anaerobic digestion is the alternative that would reduce environmental impact to greater extent in territories with medium-low waste output. From territorial point of view, thermal processes showed better outcome for WTE alternatives because of greater generation of employment, and fewer environmental requirements that make potential locations more readily available. But anaerobic digestion is the best treatment system for medium to low waste production area(Fernández, et al., 2017). Pitchayanin et al. selected Bangkok in Thailand as a representative urban city in developing countries that had experienced problems because of improper waste management. They considered that the best potential way to alleviate the impacts of improper waste management is public-private-community partnership. Later, the outcomes showed that 87.2% of respondents thought that everyone should be responsible for and be the part of waste management (Sukholthaman, et al., 2017).

Waste to Energy Technologies in the World and Thailand

Since 1990, there have been numerous WTE power plants constructed in the world. USA utilized 394 trillion Btu of energy generated from MSW while Germany constructed many WTE plants in the year 1990. Similarly, in the end of 1991, there were 102 incineration power plants in Japan which fulfilled some of their energy demand. Hence, WTE technologies have been given greater preference and advancement especially in the developed countries. USA solitary produced electricity from 77 WTE facilities up to 14.3 million MWh in the year 2014. In China, the most widely used WTE option for waste treatment is incineration technology, where approximately 268 incineration plants were in operation till 2015. Japan has around 1200 municipal incineration power plants, out of which, 234 incineration power plants are using incineration approaches to generate electricity. Similarly, South Korea and Taiwan have 39 and 24 incineration plants in operation respectively. In European countries, France is leading with 127 incineration plants followed by Germany, Italy, Sweden, Denmark and Netherland with 79, 52, 34, 29 and 13 respectively as shown in Fig. 2.

According to estimated figure by the Environmental Protection Agency (EPA), USA has recovered energy with Landfill Gas (LFG) from approximately 634 landfills in June 2017. These projects generated approximately 17 billion kWh of electricity and delivered 96 billion cubic feet of LFG to direct end users and natural gas pipelines annually. Similarly, Australia has approximately 458 operational landfills, out of which, 65 landfills with LFG energy recovery i.e., ranging in size from 400 kW to 13 MW whereas 250 landfills are operational with gas capture and flaring. Many anaerobic co-digestion plants were installed by Italy with a capacity range of 50 kW to 1 MW. Out of the total generated MSW, Iran has increased the utilization of anaerobic digestion approach from 0% in 2002 to 0.7% in 2014. In fact, this waste treatment option was implemented in only 22 regions of Tehran province.

Similarly, European Union (EU) significantly improved their waste treatment practices since 2000. Hence, incineration has been given preference over landfilling due to least environment friendly waste disposal approach and even more so by recycling and composting. EU recycled or composted around 43% of the total generated MSW in year 2013. However, South Korea, the only country to surpass EU with approximately 60% of its MSW being treated through recycling or composting. Whereas, Singapore recycled 44% of their generated wastes in Asian countries, while, typically 8%-11% wastes recycled in other developing countries. It has been reported that, 20-30% of recycling rate is achieved in some cities such as Hanoi. Recycled MSW in different regions of the world can be seen graphically in Fig. 3. Developing countries like India, Vietnam, and Malaysia utilize organic waste to recover energy, but at smaller scale. Nguyen et al. estimated that, Vietnam's electricity demands up to 4.1% could be fulfil from food waste alone using anaerobic digestion process by converting into biogas. The potential of WTE technologies has not yet been recognized by many of the developing countries(Nguyen, et al., 2014).

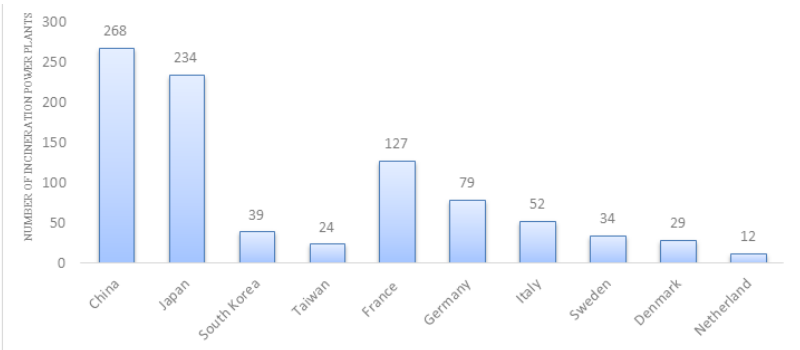

Fig. 2 Incineration power plants.

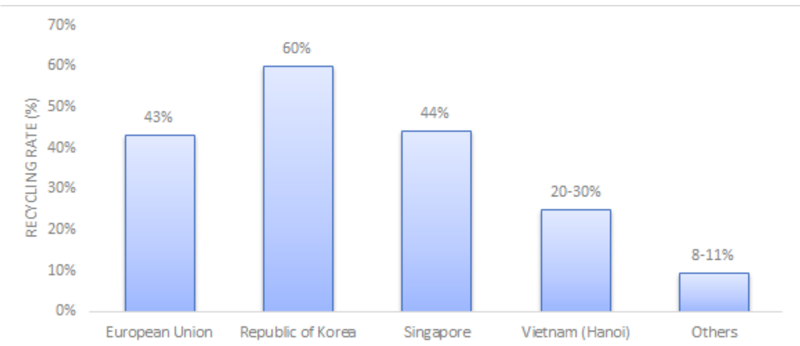

Fig. 3 Recycled municipal solid waste in different regions of the world.

In the year 2000, biogas had been utilized as the vehicle fuel and found to be one of the best practices in Stockholm, Sweden. On the other hand, the usage of biogas from MSW is common for household cooking in some developing countries. Currently, China has more than 30 million household digesters and India has 3.8 million. Poland installed 29 agricultural biogas power plants which generated an average capacity of 1 MW electricity at the end of 2012. Similarly, Canada also utilized WTE technology to recover energy from MSW and generated surplus energy of 134.6 MWh/year (Jiang, et al., 2011).

Although WTE technology historical background was found in the 1990's in the world, however Thailand started WTE landfill gas producing 600 kW electricity which is in Nakhon Pathom province in 1995. The advancement in WTE technology has been made in Thailand in past few years as a result of governments.

Contemporary development to Thailand's 2015-2036 vision, which aims at fulfilling energy requirement from the renewable energy sources up to 30% of the total demand of electricity in Thailand by 2036.

In Thailand, MSW has been found a major environmental issue like other developing countries. As reported by Pollution Control Department (PCD) approximately 27.06 million-ton MSW had been found in Thailand in the year 2017. It is estimated that 1.14 kg of waste per capita per day was generated, which is more than the average figure of other middle-income countries that is 0.79 kg as reported by the World Bank. In Thailand the most common practices of solid waste disposal currently being used are open dumping and landfill that cause air pollution, water and soil contamination, and climate change (Rizwan, et al., 2018; Lu, et al., 2017).

Department of Alternative Energy Development and Efficiency (DEDE) reported that Thailand generated 141.82 MW power from 23 WTE plants in operation till 2016 and expected to establish 18 more power plants (total increasing capacity of 115 MW) within the next two years. The WTE techniques applied in Thailand from 2010-2016 is summarized in Fig. 4.

In 2016, out of 5.81 million tons (21.47 percent) of the total waste, 5.20 million tons (89.50 percent) recycled, 0.60 million tons (10.33 percent) composted while 0.01 million tons (0.17 percent) were processed into biogas as a replacement energy source respectively. Similarly, it was estimated that there were 13.87 million tons of recyclable materials in the industrial sector such as glass, paper, plastic, metal, aluminium, and rubber, with approximately 9.93 million tons or 71.59% being reused as an alternative energy source, see Fig. 5. WTE plants have become an attractive interest for operators while most of them extended their business from rubbish collection and riddance activities. In December 2015, WTE projects sold 117.2 MW electricity to the grid including Small Power Producers (SPPs) generated 73.0 MW and Very Small Power Producers (VSPPs) generated 44.2 MW. However, the expansion of new plants is still facing challenges caused by complications with the Public-Private Partnership (PPP) Act and city planning, as well as, possible public opposition, etc (Pantaleo, et al., 2013; Rajaeifar, et al., 2017).

As of December 2017, the electricity generating capacity of Thailand's power system reached 42,433.25 MW. Electricity Generating Authority of Thailand (EGAT) power plants generated 37.87% (16071.13 MW) of the total generated electricity in EGAT system. Independent Power Producers (IPPs) shared 35.23% (14948.50 MW) including 7.65% (3247 MW), however Small Power Producers (SPPs) and imported electricity from neighbouring countries shared 17.76% (7536.02 MW) and 9.14% (3877.60 MW) respectively. On the basis of technology, combined-cycle and condensation thermal power plants counted for about 70% of the total, while renewables accounted for 17%, as illustrated in Fig. 6.

	2010	2012	2015	2016
LFG	11.97	24.52	24.52	24.52
AD	1.2	1.2	2	2
Gasification	0.2	0.44	8.45	8.45
Incineration	0	16.65	96.65	106.85

Fig. 4 Waste to energy plants in Thailand.

Fig. 5 Industrial waste being generated and utilized from 2012-2016 in Thailand.

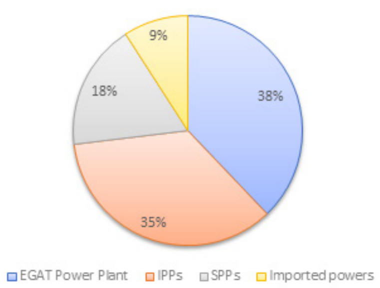

Fig. 6 Power producers share in EGAT system in Thailand.

Table 2 shows the comparison of WTE technologies used in Thailand and rest of the world as per world bank report 2012 and it illustrates that open dumping for disposal of MSW is common practice in Thailand, Asia and Africa while this method of disposal is not preferable in North America. Although sanitary landfill is the most commonly used disposal technique in North and Latin America, however it is the least favourable disposal method in Thailand. Besides, Europe leads incineration technique than rest of the world including Thailand (Ngoc, et al., 2009).

Municipal Solid Waste Management in Hat Yai

Hat Yai lies in the southern part of Thailand and is the 3rd biggest metropolitan area of the country having land area of 21 km^2 with population around 191,696. Total electricity consumption per capita in Hat Yai is around 22848 kWh annually. Dense population and industrial facilities are the major reasons behind this massive power consumption in Hat Yai. In the past, MSW generated in Hat Yai used to be collected by Hat Yai Municipality to sanitary landfill in Khuan Lang community. This sanitary landfill consists of an area about 0.22 km2 where both residual and emerging wastes were disposed. Later, a landfill of around 0.13 km2 and 0.02 km2 WTE plant was constructed. The International Engineering Public Company Limited (IEC) acquired GIDEC Company Limited in 50/50 joint venture with EGCO to operate the municipality solid WTE power plant in Hat Yai. In December 2014, the power plant started operation with power production capacity of 6.5 MW (Velis, et al., 2012). However, the installed capacity of the power plant is 6.7 MW. GIDEC Co. Ltd. made 25 years long term contract with Hat Yai municipality to daily manage 250 tonnes of waste, which is used as feedstock in Provincial Electricity Authority (PEA) electricity generation process. This is the first MSW power plant in Thailand to use advanced European technology with high standard of environmental management. According to PEA, this power plant generates around 1.3% of overall electricity demand of Hat Yai. Table 3 demonstrates the municipal solid waste’s percentage composition in four major cities in Thailand.

Process flow diagram of municipality solid WTE power plant in hat yai: The waste materials are transported by the truck scale to the garbage yard where different elements from the wastes are sorted out via sorting line and segregated with the help of trommel screen. Once the solid wastes are separated, the shredder shreds the materials down into fractional size and then carried out in combustion chamber where the materials are combusted to produce heat. The heat produced in combustion chamber is used to boil water to generate high pressure steam which enables electrical generator to produce electricity (Ojha, et al., 2012; Baran, et al., 2016). The generated electricity fulfils the operation of the power plant first, transferring the remaining power to PEA system, see Fig. 7, and Fig. 8 demonstrates the monthly electricity production in kWh in municipality solid WTE power plant in 2017. The plant generated at an average electricity of 1797 MWh per month.

Table 2. Worldwide municipal solid waste management in 2012.

Region	Open dumping per-cent(%)	Landfill percent (%)	Incineration percent (%)	Others percent (%)
Thailand	65	5	5	15
Asia	51	31	5	14
Africa	47	29	2	22
North America	0	91	0	9
Latin America	31	59	2	8
Europe	33	27	14	26

Table 3. Municipal solid waste composition in four major cities in Thailand.

Cities	Food	Paper	Plastic	Metal	Glass	Others
Rayong	42.70	9.24	17.13	4.26	0.74	25.93
Hat Yai	31.28	4.46	32.43	0.56	5.59	25.68
Korat	40	14	30	4	3	9
Chiang Mai	24	17.80	13.76	7.59	9.02	27.83

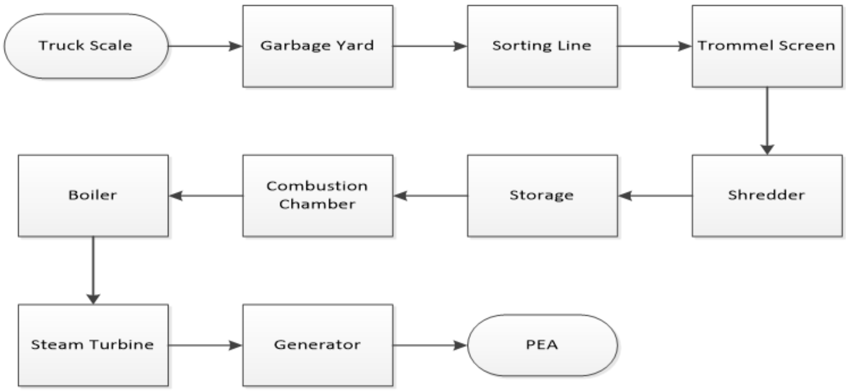

Fig. 7 Process flow diagram of municipality solid WTE power plant in Hat Yai.

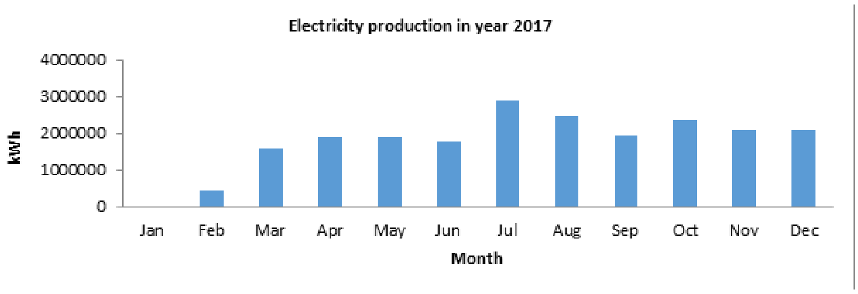

Fig. 8 Monthly basis electricity production in municipality solid WTE power plant in Hat Yai.

CONCLUSION

A comprehensive review of MSWM and WTE technologies as well as their present scenario across the world has been discussed in this paper. A thorough review of the existing WTE technologies shows that open dumping for disposal of MSW is common practice in Thailand, Asia and Africa while this method of disposal is not preferable in North America. Although sanitary landfill is the most commonly used disposal technique in North and Latin America, however it is the least favorable disposal method in Thailand. Besides, Europe leads incineration technique than rest of the world including Thailand. Although municipality solid WTE power plant in Hat Yai generates 6.5 MW or 1.3% of the overall electricity demand of Hat Yai, Thailand, however, the most viable WTE technology in Thailand is biochemical conversion due to its various advantages like controlled GHG emissions, energy recovery with production of high-quality soil conditioner, less social resistance, free from bad odour and rodent as well as less land area requirement. But, to improve biochemical conversion efficiency, it is essential to bring awareness in public about waste segregation at community level. In addition, government policies and strategies, financial support and improved technologies will support the overall MSWM and WTE technologies in Thailand.

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