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Review Of Municipal Solid Waste Management Technologies And Its Practices In China And Germany

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Abstract: Due to rapid human population in the world, high rate of consumption and urbanisation has been the result, which has led to massive increase in Municipal Solid Waste (MSW) generation. Various areas of review in this study reveals that MSW is becoming a global concern primarily in developing countries where the high cost of acquiring waste treatment infrastructures have diverted the attention of stake holders to cheap alternatives. Furthermore, review on China as a developing country revealed landfill/open dumping as a major waste management practice which does not only have the potentials of causing regional impacts such as acidification, but can also result in global impacts such as global warming which the entire world is desperately working towards minimising. Also, review on Germany as advanced country revealed recycling as the primary method of waste management practice which utilises the principles of waste management hierarchy and thus, regulations and policies on MSW handling in Germany led to zero waste disposal at landfills. Moreover, various MSW treatment technologies were assessed in terms of capital cost, effectiveness with regards to energy production and environmental impacts. The result of the assessment showed that some waste treatment technologies (incineration and pyrolysis) though cost effective, may require further development to improve the current standard to meet the waste management policies and directives. Contrary, some wastes treatment technologies such as anaerobic digestion is not versatile in terms of handling all kinds of waste, but has been proven very effective in the treatment of organic waste with minimal cost and emission potentials. However, the findings revealed that conventional gasification technology requires low capital cost with minimal toxicity in the emissions, but requires further developments in the waste treatment versatility. The study also reveals that landfill requires more developments than every other waste treatment technologies due to the drawbacks associated with the process. Finally, plasma arc gasification technology though cost intensive and not widely used, proves to be a very good option with exceptional qualities over other MSW treatment technologies.

Keywords: Waste Treatment, Environmental Impact, Energy, Emissions, Cost

1.0. Introduction

Prior to industrial revolutions in the early 1940s, materials considered as solid waste existed as organic matter and other biodegradable materials which can easily decompose into the ground when disposed (Tchobanoglous et al., 1993). As human population increased over the years, availability of land masses declined due to urbanisation and industrial revolutions. These activities have led to increasing rate of consumption which the end product is MSW generation. Although MSW provides alternative fuel for sustainable developments, it can contribute massively to environmental problems which are detrimental to the ecosystem (Lijun et al. 2014). Despite the extent of industrialization and civilization across many parts of the world, Laurent et.al (2014) mention that these human activities have generated extensive amount of hazardous waste and undecomposed materials that can only be useful if processed with proper waste management technologies. In addition, Teixeira et al. (2014) discuss that waste management system; mostly in developing countries have negative influence on the environment. Bogner et.al (2007) mention that despite the technological innovations, production decisions and waste minimization strategies put in place to remediate environmental problems caused by municipal waste in our society, waste disposal continues to raise concern in many parts of the world due to landfill scarcity for MSW disposal and lack of effective technologies to minimise this threat. The 2014 EU waste framework directives drafted by the department of environmental, food and rural affairs was developed to provide a comprehensive legislative framework to ensure that wastes are properly handled, collected, recovered or disposed without endangering public health and the environment. This legislation includes source separation, separate collection, landfill tax, permissions and inspection requirements and most developed countries including European countries, United States, Canada, Germany, Hong kong etc have considered these policies which attracts payment to municipal divisions on failure to comply with the government (Watson 2013). Reverse is the case for many developing countries where dumpsites are used primarily for waste disposal without any regulations or actions take to protect the environment from the effect of Green House Gas emissions from open dumpsite and its consequences on ground water which serves a source of drinking water in most developing nations in the world. For example, survey carried out by Ma et.al. (2014) on the waste management practice in Hangzhou, China, revealed that many Chinese residence cannot effectively separate the various kinds of waste generated. Consequently, kitchen waste which is composed of high liquid and chlorine content alongside waste materials generated from other sources are all disposed indiscriminately at open dumpsite. Shi et al. (2008) reported that over the past two decades, the vast development and urbanization in the Chinese economy has increased the rate of MSW generation between 8-10% every year. Xu et al. (2013) pointed out that increasing rate of population, thriving economies, expansive urbanization have widely increased the generation of MSW developing countries such as china. Lijun et.al (2014) discuss that fast growing population and urbanisation in the Chinese region have accelerated the ranking of MSW generation in this region to number one in the world. However, the Chinese economy in recent times is experiencing a rapid increase in solid waste generation than any other country. China outpaced United States as one of the world's most largest generators of waste in 2004, and China's annual waste generation by the end of 2030 will rise by another 150%, thereby, increasing from 190,000,000 tons in 2004 to about 480,000,000 by the end of 2030 (Jiaoqiao et al., 2007). From the following forecast, the Chinese economy may be facing great societal, economical and environmental crisis in future, if relevant actions are not taken to address the growing waste stream. Further to the rate at which MSW is generated in

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China as a developing country, the case may be different in developed countries of the world depending on the population of people. For example, Lijun et.al (2014) presented a report estimating that 1.2 billion people in China were responsible for 139 million tonnes of MSW collected in 2002, while the same report for 2010 in China shows an estimate of 158 million tonnes of MSW with human population of 1.4 billion people. However, Fischer (2013) presented a report (MSW generation from 2001-2010) for the European Environment agency under its 2012 working scheme on waste implementation. An important content of that report pointed out that approximately 51 million tonnes of waste was generated by Germany in 2002, while approximately 47 million tonnes of MSW was generated by Germany in 2010. Moreover, Population Reference Bureau (2013) reported the total population of people in Germany in 2010 to be 82 million. World Bank (2014) confirms the population of people in Germany for 2010 as approximately 82 million while reporting the German population for 2002 as 82.5 million. The EU target to meet 50% recycling of Municipal Solid Waste (MSW) has already been met in Germany, as such, MSW recycling increased from 48% of the total amount of waste generated in 2001 to 62% in 2010, while a ban on landfilling of non-segregated and untreated solid waste has taken its full stand. For example, Investigation carried out on waste management practice revealed that zero tonnes of Biodegradable Municipal Waste (BMW) were disposed at landfill in 2006, 2007, 2008 and 2009 respectively. This is because of the prohibition of non-pretreated disposal at landfills in Germany. This was introduced in two categories with the first being an administrative regulation in 1993 which reduced organic waste disposal at landfill to less than 3% of the total waste generated in Germany (EEA, 2009). The second category was two ordinances in 2001 and 2002 which focused at eliminating some of the drawbacks in the 1993 administrative regulation (EEA, 2009). Moreover, the initiative of source separation, mandatory separate collection of biodegradable waste materials and introduction of recycling bins to promote metals and plastics recycling reduced the amount of solid waste generation in Germany from 52.1 tonnes million in 2001 to 46.4 million tonnes in 2006 which later increased to 48.5 million tonnes in 2009 but decreased to 47.7 million tonnes in 2010 with almost 0% landfilled (Fischer, 2013; EEA, 2009).

2.0. Review of MSW Treatment and Disposal Methods in Germany and China

After pre-processing to separate organic or biodegradable waste from inorganic waste which are conveyed to recycling unit, while organic waste are transported to treatment facilities such as anaerobic digestion or treated alongside carbonaceous materials in thermal treatment facilities for energy recovery. Dorado et al. (2014) discuss that the major goal of MSW treatment facilities is the reduction of biodegradable organic waste via chemical and biological means. Furthermore, waste treatment facilities processes not only biodegradable MSW but also carbon based MSW such as paper, plastic, and textile via thermal processes. Waste treatment is one of the most important functional elements of the waste management system which primarily occur in locations situated far away from residential areas to avoid the toxic emissions arising from MSW treatment technologies such as pyrolysis, gasification, incineration, recycling and landfill (Singh et al. 2011). However, some developing countries have acquired some of these waste treatment facilities to help achieve its GHG emission minimisation forecast, while some are still struggling to achieve its emission minimisation goal probably because of the low income capital per head or the high cost of waste treatment facilities. For example Yang et al. (2013) cite that Germany have met its forecast on GHG reduction over MSW while the Chinese economy is facing serious problems due to the waste treatment practice utilised in this region. Lijun et al. (2014: 138) discuss that all landfill areas and operations in Germany were closed down since 2005. In addition, MSW incineration is one of the major technologies utilised in electricity generation in Germany. Tian et al. (2013) mention that out of 158 million tonnes of MSW reported in China for 2010, 79% were landfilled, 19% incinerated and 2% composted. This shows that material recycling is not practiced to a large extent as some developed countries. Lijun et al. (2014) discuss that there is very limited or almost no practice of MSW recycling in China. Moreover, Dorn et al. (2012) discuss that UN estimated forecast in 2002 reported 160 million tonnes of MSW in 2010 for China, while the 2010 Chinese Statistical yearbook reports that 80% of untreated MSW were landfilled, 16% combusted and the remaining percentage treated by other methods. Furthermore, the authors cite that MSW composition in 2009 accounts for 78% wet organic waste, 10% dry organic waste such as paper and 12% non-biodegradable waste such as plastics and metals. Zhang, Tan and Gersberg (2010) comment that while the recovery of landfill gas accounts for approximately 60% in some western countries, recovery rate of landfill gas is less than 20% in China due to poor management standard. Moreover, the authors summarise that biogas which compose mainly of methane (CH_4), has a higher global warming potential than CO_2. Further to the report in 2010, MSW composed mainly of organic waste in Germany. Muhle, Balsam and Cheeseman (2010) discuss that landfill disposal of recoverable MSW and non-pre-treated MSW is under intense restriction in Germany. The idea is designed to minimise landfill emissions into the environment and also to prevent the effect of leachate from contaminating the soil and underground water. European Environment Agency (2013) reports that the amount of biodegradable waste disposed at landfill in 2006, 2009 and 2010 in Germany was 0% in as shown in appendix 5 below. In addition, Germany aims at minimising every disposal practice while maximising recovery and recycling in 2020 (Muhle, Balsam and Cheeseman 2010). This implies that landfill technology in Germany may not be too effective in future if waste disposal are no longer practiced using this method, but energy recovery from landfill sites can still keep landfill operations running effectively. This is dissimilar to the Chinese economy where the Chinese are searching for alternative waste treatment technologies due to limited land space for landfill. Review on the current challenges posed by MSW and the management system reveals that MSW has deeply infiltrated the ecosystem with greenhouse gas emissions, potentially considered as threat to human existence as well as the environment. However, many researches have been undertaken by scholars and environmental agencies to assess these problems, causes, effects and remediation to minimise this threats emerging from MSW. Recent study on the status and prospect of MSW to energy in china reveals that the increasing volume of waste in most developing countries is becoming a problem which requires effective technology and approach to normalise the arising chaos Lijun et.al (2014). However, Xu et al. (2013) mention that although MSW is a global problem, it is more

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intense in china due to the increasing industrialization and urbanization. Teixeira et al. (2014) identified in journal of energy policy that each approach involved in MSW treatment has some benefits and disadvantages. For example, the author revealed that some waste management technologies such as unmonitored landfill and open dumpsites are responsible for the major greenhouse gases such as CO_2 and NO_X. Mavrotas et al. (2013) assert that MSW management is one of the highly challenging issues in this era, owing to the rapid urbanization in the world today. Furthermore, these authors suggest that the rapidly developing technologies and diversities in the possible route between MSW collection and disposal intensify the severity of these issues. Lack of proper waste management skills and inadequate exposure to the risk associated with each waste management element is recently emerging as a potential factor affecting the waste management system in developing countries. Due to the severity of these problems, scholars in this area of interest have investigated various existing technologies such as conventional gasification, plasma arc gasification, pyrolysis, composting, and incineration. Therefore, this study provides a general review on the sources of MSW, MSW management hierarchy, fundamental elements of the waste management system, goals and issues of MSW management system and the various technologies associated with the management system of MSW as well as the utilization of these technologies in energy recovery from waste.

2.1 Waste Management Hierarchy

The classification of waste management strategies are arranged from the most effective option in terms of environmental pollution referred to as the waste management hierarchy. This envelops all the major characteristics enhancing MSW minimisation as well as CO_2 emission through the key aspects such as reuse, recovery and recycling of MSW as shown in Figure 1.

Figure1: *Waste Management Hierarchy (Environmental Protection Department 2014)*

From the classification in waste management hierarchy, it can be observed in Figure 1, that avoidance and minimisation though difficult to achieve is ranked as first option which likely implies the most effective option for waste minimisation. Since waste avoidance and minimisation may not be possible in all cases, the second option which includes reuse, recycle and recovery (cradle-cradle) falls under the first option as shown in Figure 1. The second option is mainly practiced in advanced countries such as Germany where the problems associated with MSW have been resolved (Yang et al. 2013). In addition, the third option is the least preferred due to the negativities involved. Waste treated under the last category is classified as cradle-to-gate which implies the end of life for a particular waste material and therefore disposed at landfill sites which is widely practiced in developing countries (such as China) mainly as disposal method rather than treatment method (Lijun et al. 2014).

2.2 Solid Waste Management system and the Functional Elements

According to Igbinomwanhia (2011), waste management is a systematic plan designed to effectively control the collection, storage, transportation treatment and disposal of solid waste in our environment as shown in Figure 2. In this context, the functional elements associated with solid waste management have been categorised as shown in Figure 2;

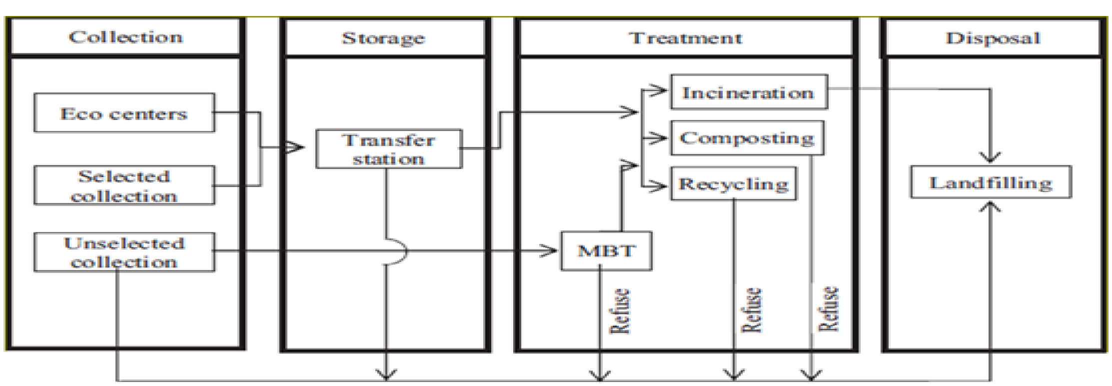

Figure 2: *Schematic overview of a conventional waste management system (Teixeira et al., 2014)*

2.3 MSW Management Technologies

MSW management technologies offer benefits such as waste minimisation and power generation. Ofori-boateng et al. (2013) argue that accomplishing an environmentally effective technology is difficult, usually when thermal technologies (Incineration, Pyrolysis, and conventional gasification and Plasma arc gasification) which apply MSW as the primary input are not designed to meet the standard of environmental protection agency. MSW management technologies can be identified as follows;

2.3.1 Plasma Arc Gasification

Jones (2014) reported that plasma arc gasification is a process that involves a high temperature pyrolysis in which organic solid waste materials (carbon based materials) are converted into a synthesis gas while the inorganic solid waste materials produces a glassy solid by-product (resembling glass beads) known as vitrified slag. However, this technology utilises limited quantity of air between 4000-7000^oC with very little or no effect on the ecosystem. The high temperature attribute of this technology is what differentiates the effectiveness of plasma arc from other technologies.

2.3.2 Conventional Gasification

Research by Murdoch University (2014) reveals that conventional gasification involves thermal putrefaction of organic waste material in a limited oxygen supply atmosphere. This technology operates within a temperature of 540-1540^oC (Stringfellow and Witherell 2014). However, the syngas produced from this technology contains mainly hydrogen and carbon monoxide with other acidic gases such as nitrogen oxides and sulphur dioxide unlike plasma arc technology were the high temperature neutralises the effect of the toxic gases.

2.3.3 Pyrolysis

Pyrolysis of MSW as described by Stringfellow and Witherell (2014) involves a thermo-chemical decomposition of organic material at a temperature of 800^o in the absence of oxygen. Martinez et al. (2013) discuss that the syngas gas product recovered from the process is not considered as a good option for internal combustion engine (ICE) operation because of the high percentage of tar present in the gas phase. This technology generates a smaller quantity of syngas with high tar content which often requires further treatment before use.

2.3.4 Incineration

Assamoi and Lawryshyn (2012) define that waste incineration is a thermal treatment technology associated with the combustion of organic substances present in waste material. The major different between incineration technology and other technologies is that incineration operates in the presence of oxygen. Therefore, the process requires excess amount of air to achieve complete combustion of the waste materials unlike conventional gasification and plasma arc gasification requires limited air supply to disintegrate the waste feed. The process involved in waste incineration generates non eco-friendly by-products that contradict with the viability of this technology.

2.3.5 Composting

The word compost relates largely to organic matters which by means of microorganisms disintegrate into organic conditioners added to the soil while generating biogas in the process. Recent study by Murdoch University (2014) reveals that composting involves two basic technologies which include aerobic digestion which takes place in the presence oxygen and anaerobic digestion which occurs in oxygen free environment. Aerobic digestion usually occur in an open environment where the acidic gases such as CH_4 and CO_2 from the treatment process are emitted into the atmosphere, unlike anaerobic digestion where the emissions are controlled and utilised effectively.

3.0 Methodology

The method that was used in the collection of data for the study was achieved by means of review, survey and observation from existing literatures and company reports on MSW management technologies. China and Germany were selected with the idea of comparing the waste management practice in the two countries as shown in Figure 3 and 4, of which Germany is an advanced country compared to China which is still undergoing development. Also, MSW treatment technologies were compared to determine which is used by any of these countries and to recommend the appropriate option that can be adopted for MSW treatment, considering environmental impacts and the cost of adopting the preferable option.

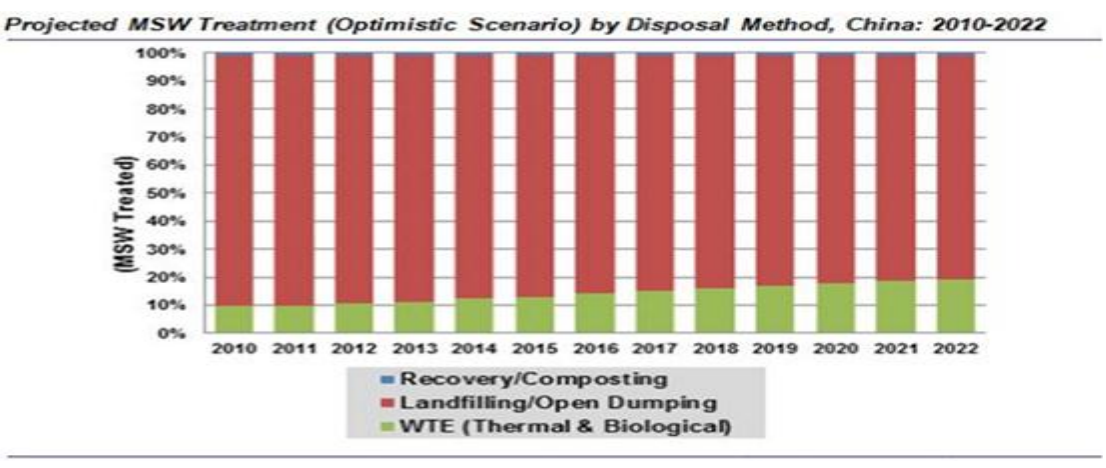

Figure 3: *Forecast of MSW Treatment Options from 2010-2022 in China (Lawrence, 2012)*

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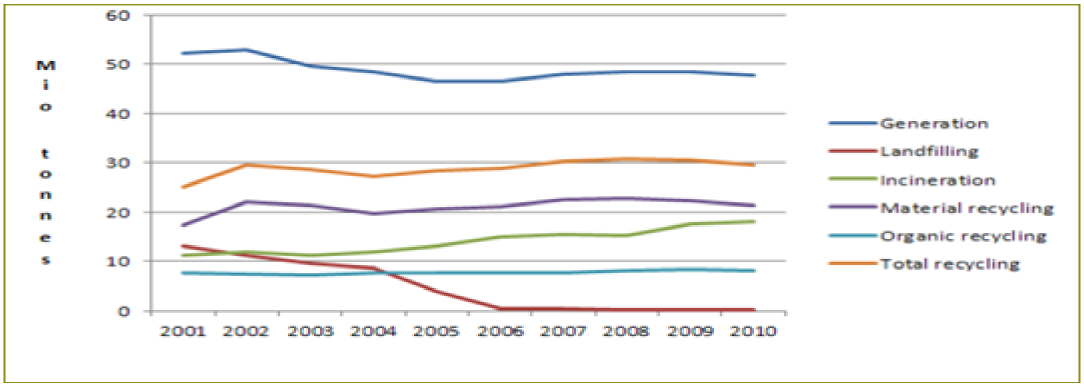

Figure 4: *MSW Generation, incineration, Landfill, and recycling Options from 2001-2010 in Germany (Eurostat, 2012)*

Considering the percentage of MSW treatment using the available technologies in China for 2010, it can be observed that out of 158 million tonnes of MSW reported as the total quantity collected in 2010, 89% were landfilled. In addition, 10% of the total amount was used for energy recovery while 1% went into recovery and composting. From Figure 3, the projection shows that landfill may always be the major option for MSW treatment in China except effective action is taken. Although WTE technologies have been projected by 10% increase in the year 2022 over the previous 10% in 2010, it is not certain that the projected plan will be met. The data also revealed that having achieved 20% of MSW minimisation using WTE treatment technologies, 79% of MSW will still end up in landfill compared to Germany where MSW operators stopped the use of landfill since mid-2006 due to the problems associated with landfill technology. Material recycling took precedence in Germany since 2006 as shown in Figure 4. Expressing this in percentage, it can be observed that out of 47 million tonnes of MSW reported as the total amount generated in 2010 in Germany, 19% was recycled as organic waste while 45% was material recycling (such as metals and glass). Furthermore, 36% was incinerated which could be for energy or without energy recovery, while 0% was reported for landfill compared to 89% of MSW landfilled, 10% MSW incinerated and 1% recovery/compost (recycling) reported for 2010 in China. Also, the operating temperature of different thermal treatment technologies is as shown in Table 1. Plasma arc gasification technology utilises the highest temperature which falls within the range of 4000 and 7000^{o}C with 816 KWh/ton of MSW as the highest amount of energy recovery compared to the operating temperature and energy (KWh) production per ton of pyrolysis, conventional gasification and incineration.

Table 1: *MSW Thermal Technologies, Operating Temperatures, Energy Production and By-products (Campos and Schubert 2013)*

Technology	Operating Temperatures	Energy Production	By-Products
Pyrolysis	650-1250°C	571 KWh/ton MSW	Raw syngas, ash, char, metal
Conventional Gasification	800-1650°C	685 KWh/ton MSW	Raw syngas, ash, slag, metals
Incineration	550-1100°C	544 KWh/ton MSW	High pressure steam, ash, exhaust gases
Plasma Arc Gasification	4000-7000°C	816 KWh/ton MSW	Raw syngas, inorganic materials, vitrified slag

To achieve a particular temperature required by the waste treatment reactor, a large amount of energy such as fuel or electricity may be exhausted depending on the power source. Therefore, more energy input may be required to compensate for the losses in order to enhance the power needed to accomplish the rate of MSW decomposition in the WTE facility (reactor). Depending on the quantity of such energy, operating cost may be considered. Furthermore, the cost evaluation for the various WTE equipments or facilities can be observed from the data shown in Table 2.

Table 2: *Cost Estimate and Performance of Various WTE Facilities (Wilson et al. 2013: 36)*

Performance Parameter	Incineration	Pyrolysis	Plasma Arc Gasification	Conventional Gasification
Capacity in TDP	250	250	250	250
Cost of Construction ($mm)	70	40	100	28
Unit Cost/KWh Capacity ($)	435	222	1000	125
Unit Cost (US$/Ton Capacity/Day)	500	160	960	112
Availability	92%	85%	80%	96%
Service Life/Design Life (yrs.)	30	20	20	30
Max Fuel Moisture (%)	Limited	No	No	Limited

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4.0. Discussion

Comparing the waste treatment technology practiced in Germany and China as shown in Figure 3 and 4 above, it can be observed that MSW management system in Germany as advanced country is more eco-friendly, due to the fact that material recycling consumes less energy and generates less emissions compared to production from virgin materials. Also, due to availability of infrastructures and advanced technology adopted against the menace constituted by MSW in Germany, the effect has been zero waste disposal in landfill, unlike China (developing country) where the waste management practice is mainly open dumping and landfill which happens to be the least preferred option in the waste management hierarchy as shown in Figure 1. However, it is possible that the waste management hierarchy as well as the fundamental elements of waste management system is likely not so effective in developing or underdeveloped countries due to technological setback and infrastructures to promote researches and problem solving innovations. Furthermore, it can be observed in Table 1 that plasma arc gasification operates between a temperature range of 4000-7000^{o}C which is exceedingly higher than other thermal technologies presented in Table 1. This implies that high capital cost is required to provide the high energy needed for MSW treatment process in plasma arc gasification. In addition, syngas and steam is also recovered from the treatment of MSW with this facility which is sold to offset the high cost of energy needed for its operation (Campos and Schubert 2013). Moreover, Energy produced in Kwh/ton of MSW from Plasma arc technology is higher than that of other thermal technologies. However, thermal technologies despite the effectivity still constitute some level of GHG emissions due to the bye products as shown in Table 1, but information gathered from the literature survey reveals that plasma arc technology generates the least or probably no emission from the treatment process (Jones, 2014). For example, the bottom ash obtained from waste incineration systems pose major problem during disposal. Anaerobic digestion is a biological waste treatment method which is different from thermal technologies in terms of operational principles and the type of waste it handles which are mainly organic materials. This is unlike plasma arc gasification which handles all kinds of waste, treat the bye product in the process and transforms it into environmentally friendly and safe product despite the high capital requirement for construction and operation as shown in Table 2.

5.0 Conclusion

Waste management practices in China and Germany was assessed in this work and it was observed that MSW has no place in landfills as material recycling has been practiced largely. In the case of China, open dumping and landfill continues to be a major waste management practice. Comparing these options effective and sustainable waste management system is practiced in Germany while the Chinese economy is likely facing challenges constituted by MSW. Also, the various Waste treatment options was investigated in this work and it was observed that plasma arc gasification technology is more effective than other options due to it numerous advantages such as the energy production of 816 KWh/ton of MSW (which is higher than that of other thermal technologies) and its ability to treat MSW with minimal effects on the environment unlike other technologies, despite the high temperature required for the treatment process. Hence, plasma arc gasification technology can emerge as the most effective treatment option for MSW if the high temperature requirement can be reduced without compromising the effectiveness and performance of the system. Furthermore, stringent policies should be implemented with regards to the amount of emissions on the environment as well as construction standards to minimise the harmful effects of MSW and its treatment options on the ecosystem.

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