POTENTIAL VALUE OF WASTE-TO-ENERGY FACILITY IN RIYADH CITY - SAUDI ARABIA

Rafat Al-Waked, rfalwaked@just.edu.jo, Department of Mechanical Engineering, JUST, Irbid, Jordan

Omar K. M. Ouda, oouda@pmu.edu.sa, Department of Civil Engineering, Prince Mohamed Bin Fahd University, Al Khobar, KSA

Syed A. Raza, snaqvi@pmu.edu.sa, Department of Electrical Engineering, Prince Mohamed Bin Fahd University, Al Khobar, KSA

ABSTRACT

Riyadh City, the Capital of the Kingdom of Saudi Arabia (KSA), has experienced far-reaching changes in spatial and socio-economic patterns during the last few decades, supported by huge crude oil revenue. The changes have produced far-reaching increase in municipal solid waste (MSW) generation and electricity demand. Open landfilling is the dominant method of MSW disposal in the city. This research aims to assess the value of Waste-to-Energy (WTE) facility as a solution to MSW landfill problem and as a renewable source of electricity. Three WTE scenarios were developed: complete incineration; incineration with recycling and Refused Derived Fuel (RDF) with Biomethanation. The results show that Riyadh has the potential to produce about 302 MW of electricity based on incineration scenario; about 19 MW based on incineration with recycling scenario; and about 147 MW based RDF with biomethanation scenario in the year 2035. These values are based on theoretical ideals and help in identifying the optimal WTE techniques for each city.

KEYWORDS: Waste-to-Energy; Municipal Solid Waste; Renewable Energy; Incineration; Refused Derived Fuel; Biomethanation, Western Province of Saudi Arabia.

1 INTRODUCTION

Riyadh City has experienced far-reaching changes in spatial and socio-economic patterns during the last few decades. Based on the enormous economic growth due to large oil reserves, there has been a rapid growth in population and urbanization [Ouda et.al., 2013; 2013b]. Populations, urbanization growth, the rise in the standards of living have all dramatically accelerated the MSW generation in City [Minghau and Xiumin, 2009; Guerrero et.al., 2013].
The Ministry of Municipal and Rural Affairs (MMRA) has forecasted that 88 percent of the Kingdom’s inhabitants will live in urban areas by 2025, which could consequently have an adverse effect on urban, social and economic development. Demographic distribution in Saudi Arabia is concentrated in Riyadh, the Western Province and the Eastern Province, as they are commercial hubs and businesses tend to proliferate in urban areas.

Riyadh is the capital of KSA and has a current population of around 6 million [CDSI, 2010]. The long term average population growth is about 3.4%. MSW management is a challenging chronic problem in Riyadh City [Nemerow, 2009]. Developing countries were not able to cope with the MSW generation growth and open landfills remains the dominant method of disposal [Ouda et.al., 2013; Ouda, 2013]. The current municipal solid waste management system in Riyadh is simple: collect and get rid of it by dumping it in open landfill sites [Ouda et.al., 2013]. The substantial quantity generated by MSW and the high energy contents of its composition demonstrate the significant potential for WTE facilities in the City [Ouda et.al., 2013].

There are primarily five WTE technologies widely used and implemented for MSW management namely: incineration with energy recovery, pyrolysis or gasification, plasma arc gasification, refused derived fuel (RDF) and biomethanation. In this study, three technologies were considered for analysis: incineration, RDF and biomethanation. Incineration is the production of energy from waste through combustion [Frigon and Guiot, 2010; Tchobanoglous et. al., 1993; Denac et. al., 1990; Kameswari et. al., 2007]. Incineration has remained to be the most integral part of MSW management in many countries. RDF is a clean and efficient method of producing an eco-friendly and an alternative fuel for power generating industries, which runs on coal fuel [Nabeshima, 1996]. Biomethanation converts the Organic Fraction of Municipal Solid Waste (OFMSW) into useful energy [Samuel et. al., 2006].

2 OBJECTIVE AND METHODOLOGY

This paper aims to assess the value of Waste-to-Energy (WTE) facility as a solution to MSW landfill problem and as a renewable source of electricity in Riyadh city. Three scenarios were considered: complete incineration; incineration with recycling; and RDF with biomethanation. The complete incineration scenario implies full utilization of MSW for WTE production. Incineration with recycling assumes removal of all potentially recyclable materials from the waste stream and utilizing the remaining MSW for WTE production. RDF with biomethanation considers segregation of general waste stream into inorganic and organic waste. The inorganic waste is then considered for RDF methodology while organic for biomethanation.

The year 2012 was chosen as the starting year for forecasting. The MSW production rate was assumed to be 1.4 kg/capita/day [Ouda et.al., 2013]. The population growth is projected to maintain its historical trend of 3.4% for year up to the year 2035 and MSW total generation for Riyadh city was forecasted accordingly.
The calorific energy content of the various types of waste is listed in Table 1 [Cheng and Hu, 2010]. These measures were used to calculate the total energy content per kilogram of Saudi municipal waste. There are a number of developed and emerging technologies that are able to produce energy from waste. The most widely used and proven WTE is the process of producing energy in the form of heat and/or electricity from waste sources via combustion [Rogoff and Screve, 2011]. The research literature has documented a combustion efficiency of 25% to 30% for operated WTE facilities in different places across the globe [Ouda et al., 2013] and around 18% for RDF [Metro Waste Authority, 2013]. Methane conversion to energy is reported to be around 30% [Samuel et al., 2006].

<table>
<thead>
<tr>
<th>Type of waste</th>
<th>Energy Content (Btu/lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mixed Paper</td>
<td>6800</td>
</tr>
<tr>
<td>Mixed Food Waste</td>
<td>2400</td>
</tr>
<tr>
<td>Mixed Green Yard Waste</td>
<td>2700</td>
</tr>
<tr>
<td>Mixed Plastic</td>
<td>14000</td>
</tr>
<tr>
<td>Rubber</td>
<td>11200</td>
</tr>
<tr>
<td>Leather</td>
<td>8000</td>
</tr>
<tr>
<td>Textiles</td>
<td>8100</td>
</tr>
<tr>
<td>Demolition Softwood</td>
<td>7300</td>
</tr>
<tr>
<td>Waste Hardwood</td>
<td>6500</td>
</tr>
<tr>
<td>Coal</td>
<td>12300</td>
</tr>
<tr>
<td>Fuel, Oil</td>
<td>18300</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>23700</td>
</tr>
</tbody>
</table>

### 2.1 Methane Estimation

The annual methane emission from Saudi’s three landfill sites can be estimated using the USEPA LandGEM model. LandGEM is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of landfilled waste in municipal solid waste (MSW) landfills. The software provides a relatively simple approach to estimating landfill gas emissions. Model defaults are based on empirical data from U.S. landfills. Field test data can also be used in place of model defaults when available.

\[
Q_{CH4} = \sum_{i=1}^{n} \sum_{j=0.1}^{1} k L_0 \left( \frac{M_i}{10} \right) e^{-kt_{ij}}
\]  

(1)

where \(Q_{CH4}\) is the annual methane generation in the year of the calculation (Gg/y), ‘i’ is the 1-year time increment, ‘j’ is the 0.1-year time increment, ‘n’ is the (year of the calculation) - (initial year of waste acceptance), ‘k’ is the methane generation constant (y-1), \(L_0\) is the potential methane generation capacity (m3/Mg), ‘\(M_i\)’ is the mass of waste accepted in the ith year (Mg), ‘\(t_{ij}\)’ is the age of the jth section of waste mass ‘\(M_i\)’ accepted in the ith year.
2.2 Calculations for heat to power generation potential

In order to evaluate the energy generation potential from MSW, table 1 is used to calculate the lower heating value of the waste by considering the dry solid waste without moisture content. For bulk incineration process the average value of the total waste is considered as a lower heating value while for incineration with recycling, all types of waste that could be recycled are excluded from the calculations. In case of RDF with biomethanation, the waste is segregated between organic and non-organic waste. In order to calculate the LHV for this process, the organic waste is excluded from the general stream and the calculations are performed on the remaining waste stream including paper, plastic, glass, wood, textiles and others. The energy recovery potential (GWhr/day), Power generation potential (MW) and Net generation potential (MW) are given by equations (2)-(4).

\[ \text{Energy Recovery Potential (GWhr/day)} = \frac{(\text{Dry waste (tones/days)} \times \text{LHV of waste (kWh/kg)})}{1000} \]  

(2)

\[ \text{Power Generation Potential (MW)} = \frac{(\text{Dry waste (kg/days)} \times \text{LHV of waste (kWh/kg)})}{1000} \]  

(3)

Net Power Generation Potential (MW) = \( \eta \) * Power Generation Potential  

(4)

where \( \eta \) is the efficiency of the process. Efficiency for incineration is taken as 25% and for RDF is taken as 18%.

2.3 Heat to power generation potential calculation by biomethanation process

The biomethanation process is preferred for organic waste stream with moisture content to allow for microbial activity. The typical conversion efficiency for this process is taken as 30% [Gotmare et. al., 2011]. The values for the total land fill gas (LFG) generation are taken for LandGEM model.

\[ \text{Power Recovery Potential (MW)} = \frac{(\text{Total Methane Generation (m}^3/\text{day}) \times \text{NCV} \times 365.25)}{(0.042 \times 1000 \times 24)} \]  

(5)

\[ \text{Net Power Generation Potential (MW)} = \frac{\text{Total Methan Generation (m}^3/\text{day}) \times \text{NCV} \times \eta \times 365.25}{1000} \]  

(6)

Where NCV is the Net Calorific Value of LFG and lies in the range 0.194-0.242 kW/m3 and \( \eta \) is the efficiency for the bio-chemical process.
3 RESULTS AND DISCUSSION

3.1 MSW Composition and Quantity Forecast

The waste composition for Saudi Arabia is tabulated in the table 2 along with the LHV values for each type of waste using the values from table 1. The MSW wastes consists of 37% organic materials, 28.5% paper, 5.2% plastics, 8.3% mineral, 4.6% glass, 8% wood, 6.4% textile, and 2% others [Ouda et.al., 2013; AFED, 2008].

Table 2: Saudi MSW energy content

<table>
<thead>
<tr>
<th>Material</th>
<th>Waste Composition (%)</th>
<th>Energy Content (Btu/lb)</th>
<th>kW.hr/kg in Material</th>
<th>kW.hr/kg in Waste LHV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paper</td>
<td>28.5</td>
<td>68000</td>
<td>4.39</td>
<td>1.21</td>
</tr>
<tr>
<td>Plastic</td>
<td>5.2</td>
<td>14000</td>
<td>9.05</td>
<td>0.46</td>
</tr>
<tr>
<td>Glass</td>
<td>4.6</td>
<td>0</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Wood</td>
<td>8</td>
<td>7300</td>
<td>4.73</td>
<td>0.24</td>
</tr>
<tr>
<td>Textiles</td>
<td>6.4</td>
<td>8100</td>
<td>5.20</td>
<td>0.22</td>
</tr>
<tr>
<td>Organic</td>
<td>37.0</td>
<td>2400</td>
<td>1.55</td>
<td>0.10</td>
</tr>
<tr>
<td>Others</td>
<td>10.3</td>
<td>5200</td>
<td>3.36</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Total energy for Mass Burn with recycling scenario (kW.hr/kg) 0.3772

Total energy content of Mass Burn scenario (kW.hr/kg) 2.5121

The forecasted MSW quantity per year for Riyadh city up to year 2035 is presented in Figure 1. The figure shows that by the year 2035, about 6195 thousand tons of MSW. This is a huge quantity and should be managed properly otherwise a severe environmental consequence can be anticipated in the long-term.
3.2 Methane Gas Generation

For the estimation of methane from the landfill sites, user specified inputs are used in the LandGEM model. The methane generation potential, \( L0 \) has been specified as a default value of 61 m\(^3\)/Mg, while the methane generation constant \( k \) has been specified as 0.026 per year. The methane and carbon dioxide in the LFG have been considered to be 50%. For the purpose of this study it is assumed that the landfill site in Riyadh started operation in 2012 and the waste is accumulated up to the year 2035. Biomethanation for this study is applied with RDF which takes in organic waste as input. The result for the total LFG generation in the landfill sites is shown in figure 2. The total LFG for Riyadh has been calculated as 118 Mg/year. The methane generation for Riyadh has been calculated as 87 Mg/year and for carbon dioxide as 30 Mg/year.

3.3 WTE Scenario results

Three scenarios for WTE development were developed and analyzed: complete incineration; incineration with recycling; and RDF with biomethanation. The forecast results for three scenarios for Riyadh city is presented in figure 3. The figure shows that for the incineration scenario has a potential to generate about 302 MW in 2035 while incineration with recycling scenario shows a potential to produce about 19 MW in 2035. The RDF with biomethanation scenario shows a potential to produce about 147 MW in 2035 from Riyadh.

The figure also shows that complete incineration scenario has the highest power generation capacity over the other three scenarios. Additionally, the three scenarios provide a viable disposal option for MSW and, if implemented, will alleviate the landfills problem in the area. The decision to select among the three scenario will required further financial, social,
technical, and environmental analysis. The decision to select between the two scenarios is crucial and should be taken at a political level based on the results of intensive research.

Figure 2: Landfill gas emission estimation for RDF with Biomethanation technology for Riyadh site for the years 2012-2152.

Figure 3: Power Generation Potential (MW) for Riyadh City for the years 2012-2035.

4 CONCLUSION

The MSW practices in Riyadh city are simple: collect and dump in the nearest open landfill. This practice has created a chronic MSW disposal problem in City. This research assessed the value of Waste-to-Energy (WTE) facility as a solution to MSW landfill problem and as a
renewable source of electricity in Riyadh city. Three scenarios for WTE development were developed and analyzed: incineration, incineration with recycling and RDF with biomethanation. The scenarios were forecasted up to year 2035. The research results show that Incineration Scenario has the highest power generation capacity over the other three scenarios. Additionally, the three scenarios provide a viable disposal option for MSW and, if implemented, will alleviate the landfills problem in the area. The decision to select among the three scenarios will require further financial, social, technical, and environmental analysis. The decision to select between the two scenarios is crucial and should be taken at a political level based on the results of intensive research.

5 REFERENCES


