Techno-economic assessment of municipal solid waste incineration plant-case study of Tehran, Iran

CONFERENCE PAPER · JANUARY 2015

Ehsan Haghi
Sharif University of Technology

Techno-economic assessment of municipal solid waste incineration plant-case study of Tehran, Iran

Farzad Bazdidi Tehrani[1] , Ehsan Haghi[2]

[1]Professor, School of Mechanical Engineering, Iran University of Science and Tehnology; bazdid@iust.ac.ir
[2] Mechanical Engineer, School of Mechanical Engineering, Iran University of Science and Tehnology; haghiehsan@yahoo.com

Abstract
Techno-economic assessment of municipal solid waste incineration (MSW) plant is discussed in the present paper for the case study of Tehran, Iran.
First of all, the appropriate technology for incineration is choosen and the investment and operating costs are estimated. Then, by using Tehran MSW properties, the available energy from waste is calculated. Combining the aforementioned results, LCOE[1] of an MSW incineration plant is estimated. Results show a high LCOE for an electricity generating MSW incineration plant due to the expensive technology and low heating value of Tehran MSW. However it should be noted that employing an incineration plant is an efficient method for the waste disposal while it generates power at the same time. This advantage makes MSW incineration plant noteworthy for the future research.

Keywords: MSW, heating value, incineration, LCOE

Introduction
Low environmental impact waste management systems that are capable of protecting the inhabitants health and safety are currently gaining more attention globally. There is also a great interest in new energy generation methods due to increasing demand and limitability of conventional energy sources such as fossil fuels [1],[2].
Incineration is a known method for waste disposal. Also in recent years incineration plants as well as other waste-to-energy methods like gasification and pyrolysis has been of great attention [3].
These considerations seem more important while it is estimated that near 7000 tons of MSW is produced per day in Tehran and most of it is disposed by inapproppriate methods. Also the need for sustainable energy is becoming an emerging concern in Iran [4].
Considering these issues, the objective of this paper is to assess electricity generation in an MSW incineration plant in Tehran, Iran. However, the final results can be considered reliable for other cities in developing countries, especially in the Middle East, which have similar MSW composition and similar solid waste management actions.

MSW incineration technologies
There are two common type of wate incineration furnace. Moving grate furnace and fluidized bed furnace. These two furnaces differ in many aspects. A description of both types of furnaces is as follows.

[1] Levelized Cost Of Energy

In a moving grate furnace fuel enters at top of the furnace. While moving, fuel is first dried and is then burned as ash is gathered at the bottom. Air is added primary from under the grating and secondarily above the fuel. This is done for complete contact between fuel and air ("Figure 1").

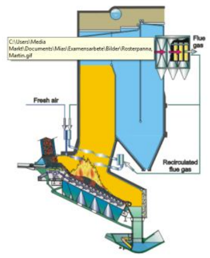

Figure 1. A moving grate furnace [1]

Fluidized bed furnace uses an inert material like sand in which fuel is distributed. There are two kinds of fluidized bed furnaces: bubble fluidized bed (BFB) and circulating fluidized bed (CFB).
In a BFB furnace, as shown in "Figure 2". air flow is in the range of 0.9-3.1 m/s which makes the bed of fuel and inert material fluidized.

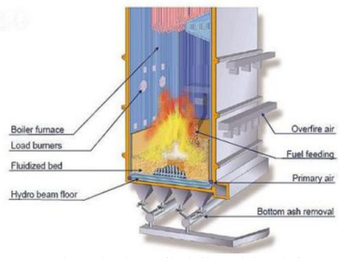

Figure 2. Circulating fluidized bed furnace [1]

A CFB furnace is shown in "Figure 3". Air flow rate is in the range of 4.9-9.1 m/a in a CFB furnace. A cyclone is placed in the outlet which separates inert and exhaust gases. Inert is then recirculated in the furnace.

Figure 3. Bubbling fluidized bed furnace [1]

Besides the combustion techniques in moving grate and fluidized bed furnace, there are two more differences.

The combustion temperature is higher in moving grate than in fluidized bed furnace. Also the fluidized bed furnace needs homogeneous particle size of the fuel to enable fluidizing.

Smedberg [1] has compared different technologies of MSW incineration plant including circulating fluidized bed, bubbling fluidized bed and moving grate. Although the conclusion showed all those technologies are economically feasible, a CFB furnace can be more financially feasible at a short depreciation time while a large grate furnace can be better at longer depreciation times. But it was also concluded that a moving grate furnace is financially more feasible regardless of depreciation time. Besides the fluidized bed is an advanced technology and may not be available in Iran. Furthermore, moving grate furnace is the most widespread and well-tested technology for incinerating MSW. Since considering the use of a moving grate furnace seems more reasonable [5],[6].

MSW heating value

There are different options for energy harvesting from MSW which are process steam, district heating and electricity. The only options considered here is obtaining electricity from MSW, therefore the results can be compared with other energy systems. Furthermore, the feasibility evaluation of an MSW incineration plant producing electricity can be more beneficial while district heating and process steam may not be applicable widespread.

The first step in calculating the obtainable electricity from MSW is evaluating MSW heating value. Considering this issue, physical analysis of Tehran MWS should be known which is given in "Table 1":

Table 1. Tehran MWS composition. [4]

composition	Mass percent	composition	Mass percent
Food and organic waste	74.56	Leather and rubber	1.11
Plastics	6.25	Wood	1.82
Textiles	3.29	Metals	2.48
Paper & cardboard	5.04	Glass	2.03

For calculating the total heating value of MSW, $H_{sup,DS}$ must be determined. $H_{sup,DS}$ or the upper (superior) heating value of a fuel defined as the energy content released per unit mass of dry sample through total combustion of the fuel, can be obtained from DIN 51900 which is available in the literature and is given in "Table 2".

The ash and water free calorific value (H_{awf}) expresses the lower calorific value of the combustible fraction and is then determined according to the following formula:

$$H_{awf} = \frac{H_{sup,DS}}{(1-A) \times MCW \times 2445} \quad (\frac{kJ}{kg}) \qquad (1)$$

where A is the ash content per kg dry sample and MCW is the weight of the condensed water per kg dry sample.

The lower calorific value of a fuel may then be calculated from the following:

$$H_{inf} = H_{awf} \times C - 2445 \times W \quad (\frac{kJ}{kg}) \qquad (2)$$

Where C is combustible fraction (ignition loss of dry sample) and W is moisture of raw waste.

The overall low heating value can be obtained by following formula:

$$H_{overall,in} = \sum m_i \times H_{i,in} \quad (\frac{kJ}{kg}) \qquad (3)$$

Using aforementioned formulas and properties of MSW composition, one can calculate the lower heating value of a specific MSW composition.

Table 2 MSW composition properties. [6]

composition	Moisture W (%)	Ash A (%)	Combustile C (%)	H_{awf} (kJ/kg)	H_{inf} (kJ/kg)
Food & organic waste	66	13.3	20.7	17,000	1,192
Plastics	29	7.8	63.2	33,000	20,144
Textiles	33	4	63	20,000	11,789
Paper & cardboard	47	5.6	47.4	16,000	6,440
Leather & rubber	11	25.8	63.2	23,000	14,265
Wood	35	5.2	59.8	17,000	9,310
Metals	6	94	0	0	-147
Glass	3	97	0	0	-73

Some fractions like inerts and fines have not been considered due to their negligible impact on the total compostion. The overall low heating value of Tehran MSW is estimated to be 3182.8453 kJ/kg.

Energy from waste

MSW is the fuel for an MSW incineration plant, so the energy obtainable from MSW in a steam power plant should be calculated. This is done in two steps: first the obtainable energy from a specific MSW is calculated. Then the power generated from the energy through a steam power plant can be estimated. Using the results, power generation potential of Tehran MSW can be estimated..

Fobil et al. [8] have presented a method for calculating waste-to-energy conversion efficiency. This method uses lower heating value of MSW and its moisture content for calculating waste-to-energy conversion efficiency.

Based on this method net energy output of MSW combustion is calculated using following formula:

$$N_e = G_{te} - E_d \ (kJ) N_e = G_{te} - E_d (kJ) \qquad (4)$$

Where N_e is net energy, $G_{te}$$G_{te}$ is gross total annual energy and E_d is energy required in drying the waste.

G_{te} can be obtained using the following formula:

$$G_{te} = m \times LHV \ (kJ) \qquad (5)$$

Where m is MSW mass and LHV is the lower heating value of MSW.

The energy required for drying MSW to a constant weight (Ed) is given by the sum of the energy required to raise the temperature of the water in waste from its initial

temperature to a vaporisation temperature of 100°C and the energy required to completely vaporises the water in the waste at 100°C or heat of vaporization.
So E_d can be obtained using following formula:

$$E_d = HI + HV \ (kJ) \quad (6)$$

$$HI = m_w \times c_w \times \Delta T \ (kJ) \quad (7)$$

$$HV = m_w \times h_f \ (kJ) \quad (8)$$

Where HI is the heat required to increase water temperature from ambient temperature (25 C^0) to 100 C^0, m_w is water mass in kg, c_w is water heat capacity in kJ/kg.K , ΔT is temperature difference and h_f is water heat of vaporization in kJ/kg.

Power generating efficiency
Ekstrand and Wänn [1] have suggested a T-S diagram for a power generating section of a MSW incineration plant.

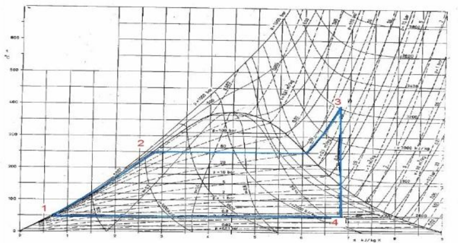

Figure 4. T-S diagram for a power generating section of a MSW incineration plant [1]

Considering the plant and the suggested diagram shown in "Figure 4"., power generating efficiency can be calculated using following formula:

$$\eta_{el} = \frac{h3 - h4}{h3 - h1} \quad (9)$$

Using equation (10) η_{el} will be 0.296.
Considering turbine and generator efficiency (η_t and η_g) as 91% and 95%, the total efficiency of power generating section is calculated using following formula:

$$\eta_t = \eta_{el} \times \eta_g \times \eta_t \quad (11)$$

Using equation (12) η_t will be η_t0.25.
As shown in the obtainable energy from Tehran MSW is 69.03% of it's heating value and the efficiency of the suggested power generating system is 25% so the total power generating efficiency is 17.25%.

Plant costs
Costs related to an MSW incineration plant arw composed of investment and operating and maintenance Costs.
The actual investment cost for a waste incineration plant depends on a wide multiple factors, namely the size of the plant, the lower heating value of the waste, land purchasing price, etc. Investment cost of an MSW incineration plant may be estimated as a function of the number of metric tons per year or day of the plant.

$$I = 2.3507 \times C^{0.7753} \quad (13)$$

Where I is the investment cost in million dollars and C is the plant capacity (1000 metric tons of waste/year).

This estimation is based on some preconditions corresponding to a typical plant configuration applicable for case study of Tehran, Iran. Comparing this correlation with the investment cost of the MSW incineration plant in Mazandaran in north of Iran shows a 3 percent variation which is acceptable for a cost estimation.
Operating and Maintenance Costs consist of fixed operating costs, variable operating costs and maintenance costs.
Fixed operating costs includes cost of administration and salaries and can be estimated at 2 percent of the total investment. Variable operating cost is a sum of cost of chemicals for the flue gas cleaning system,
Cost of water and handling of waste water and cost of residue disposal. The overall variable operating costs are estimated at US$17 per metric ton of waste incinerated.
According to customary practice, the annual maintenance costs are estimated at 1 percent of the investment for the civil works plus 2.5 percent of the investment for the machinery.
According to aforementioned items, operating and maintenance cost can be estimated by the following formula:

$$A = 0.0744 \times C^{0.8594} \quad \textbf{(14)}$$

Where A is the annual operating and maintenance cost in million dollars per year and C is the plant capacity (1000 metric tons of waste/year).

Benefits
The system product is electricity only as was mentioned before which is generated at a the efficiency of 17.25% as calculated before.

LCOE (Levelized cost of energy)
Levelized cost of energy is calculated using following formula:

$$LECO = \frac{\sum_{t=1}^{n} \frac{I_t + F_t + M_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (15)$$

Where I_t is investment cost in year t, M_t is operation and maintenace cost in year t, F_t is fuel cost in year t, E_t is electricity generated in year t, r is discount rate and n is plant life.

Results and discussions
A plant factor of 7500 hours and a plant life time of 20 years is used in LCOE calculation. Plant capacity is considered to be 80,000 tons per year (maximum plant capacity[6]).
LCOE is calculated in 3 scenarios. The scenarios are as follows:

1. Considering all fractions of MSW as plant fuel
2. Extracting valuable fractions of MSW (glass,metals and plastics) and using remaining fractions as fuel.

3. Extracting valuable fractions of MWS and complice the plant with advanced-level emission control to be adjusted with strict pollution regulations.

Calculated levelized cost for 3 scenarios is shown in "Table 3".

. Table 3. Calculated levelized cost for 3 scenarios

Scenario	LCOE ($/kWh)
1	0.9597
2	1.3589
3	1.3994

From the table 3 , the levelized cost of electricity generation in a MSW incineration plant is rather high in comparison with the other energy systems. This high levelized cost is mainly because of three reasons:

1. Due to strict pollution regulations regarding MSW incineration plants, using advanced technology for pollution control results in high levelized cost of electricity.
2. MSW incineration plant is generally an expensive facility Since it uses a low heating value fuel (in comparison with coal or natural gas) for generating electricity, LCOE is higher than conventional systems.
3. Lower heating value of Tehran MSW is rather low due to high moisture content. This decreases the maximum obtainable energy from MSW. However there are some simple methods for decreasing moisture content and hence increasing heating value of MSW. Ekstrand and Wänn [1] reported a 3 to 4 day of MSW storage can increase heating value by 1 MJ/kg. This will not add extra investment cost for the plant but can decrease LCOE significantly.

Conclusions

MSW incineration has a dual application. It is a MSW treatment method with numerous advantages over conventional methods such as land-filling. Another application of MSW incineration is the energy generation which has been investigated in this paper.

Results show a high levelized cost of electricity for MSW incineration plant. Although this high LCOE may make MSW incineration plant infeasible, some considerations may help depicting MSW incineration benefits.

1. Some simple methods can be employed for increasing MSW heating value such as solar drying which can decrease LCOE significantly.
2. Due to low heating value of MSW, other energy generation options should be considered like district heating and steam generation.
3. The role of MSW incineration as a MSW treatment method should be noted. The cost associated for energy generation is allocated for waste disposal at the same time.

As a result it can be obtained that despite high LCOE for MSW incineration plant, further research should be noticed due to its dual advantage as a waste disposal and energy system at the same time.

References

[1] Abduli, M.A., Abolghasem, N., Yonesi, M, and Akbari,A., 2011. "Life cycle assessment (LCA) of solid waste management strategies in Tehran: landfill and composting plus landfill". Environmental Monitoring and Assessment, 178, pp. 487–498.

[2] Mendes, M., Aramaki, T., & Hanaki, K., 2004. "Comparison of the environmental impact incineration and landfilling in São Paulo City as determined by LCA". Resources Conservation and Recycling, 41, pp. 47–63.

[3] Sivapalan, K., Yunus, M.N.H, Sopian, K., Samsuddin, A.H., 2003, "Energy potential from municipal solid waste in Malaysia". Renewable Energy, 29, pp. 559–567.

[4] Nabizadeh, R., Heidari, M., Hassanvand, MS., 2008, "Municipal Solid Waste Analysis in Iran". Iranian Journal of Health and Environment, 1, pp.9-18.

[5] Masters thesis, Smedberg., M, A., , 2009, "Evaluation of fluidized bed furnace and moving grate furnace for incineration of municipal waste ". MS Thesis, Lund institute of technology, MA, April. See also URL http:// www.lth.se.

[6] Tech report, World Bank, 1999. Municipal Solid Waste Incineration . August, See also URL http:// www.worldbank.org

[7] Masters thesis, Ekstrand, S., Wänn, A., , 2008, "Waste Incineration Plant in Wuhan, China - A Feasibility Study ". MS Thesis, Uppsala University, MA, April. See also URL http:// www.uu.se.

[8] Fobil, J.N., Carboo, D., Armah, N.A., 2005, "Evaluation of municipal solid wastes (MSW) for utilisation in energy production in developing countries". International Journal of Environmental Technology and Management, 5, pp. 76-86.

[9] Tsaia, W.T., Chou, Y.H. Author, A., 2006. "An overview of renewable energy utilization from municipal solid waste (MSW) incineration in Taiwan". Renewable and Sustainable Energy Reviews, 10, pp. 491–502.

[10] Quina, M.J, Bordado, J.C.M, and Quinta-Ferreira, R.M, 2011. Air Pollution Control in Municipal Solid Waste Incinerators, *The Impact of Air Pollution on Health, Economy, Environment and Agricultural Sources,* 1st ed., University Campus STeP Ri, Slavka Krautzeka 83/A, 51000 Rijeka, Croatia. Chap 16, See also URL: http://www.intechopen.com/books/the-impact-of-air-pollution-on-health-economy-environment-and agricultural-sources/air-pollution-control-in-municipal-solid-waste-incinerators.