Comparative Analysis of Incineration and Gasification of Zawia′S Municipal Solid Waste (Msw) to Produce Electricity

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Abstract:

This paper presents an overview on different municipal solid waste (MSW) systems (waste to energy systems), which are recognized as a renewable source of energythat could be implemented in Zawia city-Libya, pointing out the main advances, setbacks and challenges. The focus was on two popular methods of MSW systems which are incineration and gasification taking into account the impact of CO_2 *emission to the environment.The management of MSW is based on an understanding of MSW′s composition and its physicochemical* *characteristics, therefore the total amount of MSW produced in Zawia city was estimated and analysed. The MSW's heating value was also evaluated as 10293 kJ/kg. The results of the study show that gasification of 400 tons/day of Zawia's MSW produces about 12 MW of Electricity while Incineration produces 6.14 MW, CO_2 emission from gasification process was 9.041 tons/hr (216.984 tons/day) which is half the CO_2 emission from incineration which is 18.08 tons/hr (433.968 tons/day).*

Keywords: *Libya, Zawia, MSW, heating value, incineration, gasification, waste management.*

Introduction.

The massive increase in the amount of waste materials, due to population growth and higher average income, has harmfully and potentially affected the general environment and public health. According to the World Bank, the world currently generates about 4 billion tons of all types of waste per year. Currently, three-fourths of this waste is disposed of in landfills, with only one fourth being recycled. [1]

This issue particularly affects third world countries such as Libya where these countries face a huge challenge in constructing operational and sustainable solid waste management systems. This has led to an increasing awareness about an urgent need to adopt scientific methods for safe disposal of wastes in these countries. [2-10]

While there is an obvious need to minimize the generation of wastes and to reuse and recycle them, the technologies for recovery of energy from wastes can play a vital role in solving this problem. These technologies can lead to a substantial reduction in the overall waste quantities requiring final disposal, which can be better managed for safe disposal while meeting the pollution control standards.

Globally, wastes are used for recycling and electricity generation. Nowadays different types of waste-to-energy (W-T-E) schemes are available through which energy can be efficiently recovered and used.[11-16] Each type of technologies handles the specific composition and quantity of solid waste.[17] It seems to be difficult to propose suitable waste management plans and technologies without determining the quantity and composition of generated waste.

Due to lack of resources, data bases and ability to plan in third world countries, it is difficult to implement MSW systems without previous studies. Therefore there is a great need for investigations of economical and environmental friendly solid waste management systems that could be implemented in these countries. The main aim of this work is to compare the technical feasibility and environmental impacts of different municipal solid waste (MSW) management systems (namely gasification and incineration technologies) to be implemented in Zawia city in Libya.

2. Methodology

2.1. The Annual MSW generation rate in Zawia city

Estimates of amounts of municipal solid waste generated in Libya vary from one study to another as very few studies were carried out in this area. In the absence of accurate data on municipal waste generation, the study will use Tripoli Public Service Company (TPSC) data as a standard to calculate the quantities of solid waste generated.

The total MSW generation in Zawia municipality was calculated using the average per capita household waste generation rate in Tripoli. According to previous study [18] which was conducted by the Tripoli public services company in 2009, Tripoli residents produce about 2,500 tons of garbage daily; the average per capita household waste generation rate was 1.6 kg per person per day or approximately 600 kg per person per year. [18]By assuming that Libyan cities have similar average per capita household waste generation rate and a population of Zawia City is about 250000 citizens.

Thus the total daily MSW generation in Zawia municipality is:

1.6* 250000/1000 = 400 tons per day, which means Zawia city producesabout400 tons of garbage per day (146000 tons/year)

2.2. The composition of MSW in Zawia city

The composition of MSW is closely related to the residents, level of economic development and lifestyle. In general, the composition of MSW in Libya consists of six major categories of waste: organic matter, paper–cardboard, plastics, glass, metals, and miscellaneous.

There is no unique figure for the physical composition of municipal solid waste in Tripoli city. The national and local government organizations employed the results of different studies carried out on Tripoli city in recent years.

However, the literature on municipal solid waste composition (Table 1) indicates that the organic fraction is the predominant component in waste generated. This is followed by plastics materials and paper; other important constituents of the waste stream are textiles, metals and glass.

The hydrocarbon formula $C_6H_{10}O_4$ most closely approximated the mix of organic wastes in MSW. Therefore, in this study MSW was approximated by the formula: $C_6H_{10}O_4$

As mentioned earlier, **TPSC** conducted a study on waste generation and composition in Tripoli in 2009. Table 1 below shows the average waste composition for Tripoli residents. Zawia MSW was assumed in this study to have the same composition as Tripoli MSW in 2009.

Table 1.The waste composition in wt% for Tripoli's inhabitants in different years [18].

Component /year	1971	2002	2008	2009
Organic material	48.8	52.6	56.3	52.8
Plastic	19.5	16.9	10.0	12.4
Paper & cardboard	2.1	13.2	13.5	11.4
Metal	3.8	7.8	3.7	5.8
Textile	3.1	4.2	10.8	4.1
Wood	1.9	1.3	0.8	0.8
Glass	3.3	2.5	2.6	2.5
Miscellaneous	16.7	1.4	2.0	10.2

Table 2 shows that the organic matter forms 52.8% of the MSW followed by plastic 12.4%, Paper and cardboard which have the higher heating value accounted for 11.4 %. Metal and glass which no have heating value accounted for 8.3 % of the collected MSW. Textile 4.1%, miscellaneous 10.2%, and wood 0.8%.

Table 2.The average waste composition for Zawia's inhabitants.

Component	Wt %
Organic material	52.8
Plastic	12.4

Paper and cardboard	11.4
Metal	5.8
Textile	4.1
Wood	0.8
Glass	2.5
Miscellaneous	10.2

2.3 Overall gross energy content of Zawia MSW

The total overall gross energy content or the heating value (HV) of MSW was calculated based on the dry weight basis can be estimated from the following equations:

$$HV = \sum_{i}^{n} Xi \times HVi$$

Where:

Xi is the weight fraction of MSW category i

HVi is energy content or the heating value of MSW category i

2.4 Energy balance

2.4.1 Incineration process

The power generated (GJ/h) by waste can be calculated by multiplying the heating value of waste by the total amount of waste generated per person per day. [23]

$$\text{total amount of generated waste}\ \frac{\text{ton}}{\text{day}} \times \frac{\text{day}}{24\ \text{h}} \times \frac{1000\ \text{kg}}{\text{ton}} \times \text{heating value of waste}\ \frac{\text{MJ}}{\text{Kg}} \times \frac{\text{GJ}}{1000\text{MJ}}$$

At almost all municipal waste incineration plants, the heat produced during incineration is utilized for steam generation.

Assuming that steam at 3.14 MPa (abs) and 300°C is generated, steam Enthalpy under these conditions is 2.99 MJ/kg

From literature, combustion efficiency of incinerator is 80% [19]

The heating value of steam and its flow rate can be evaluated as following:

$$\text{heating value of steam} = \text{combustionefficiency} * \text{heating value of MSW}$$

$$= 0.8 \times 171.552 = 137.241\,\frac{\text{GJ}}{\text{h}}$$

Production rate of steam = heating value of steam /Enthalpy

$$\frac{137.241}{2.99} = 45.9\ \text{t/h}$$

This steam enters the turbine/generator, Electrical generation efficiency for the turbo generator is thus 16.1%.

$$\text{power generated by steam} = \text{electrical generation efficiency} * \text{heating value of steam}$$

$$= 0.161 \times 137.241\frac{\text{GJ}}{\text{h}} = 22.096\frac{\text{GJ}}{\text{h}} = 6.14\ \text{MW}$$

$$= 6.14\ \text{MW} \times 365\ \text{day} \times 24\ \text{hr} = 53786\ \text{MW.hr per year}$$

2.4.2 Gasification process

It has been stated that MSW can be approximated by the formula: $C_6H_{10}O_4$. Gasification by means of partial combustion with oxygen at 800^0C (assuming no reactor heat loss):

$C_6H_{10}O_4 + 3O_2 \rightarrow 3CO + 3CO_2 + 4H_2 + H_2O$ + 1300 kWh per ton of MSW [22]

The heating value of MSW is:

$$400\frac{\text{ton}}{\text{day}} \times \frac{1300\ \text{kwh}}{\text{ton}} \times \frac{\text{day}}{24\text{h}} \cong 22\text{MW}$$

Steam will be generated at the gasifier with similar combustion efficiency to the incinerator (combustion efficiency = 80%)

The heating value of steam and its flow rate can also be evaluated as following

$$\text{heating value of steam} = \text{combustion efficiency} * \text{heating value of SW}$$
$$= 0.8 \times 22 = 17.6\ \text{MW}$$

This steam enters the turbine/generator; Electrical generation efficiency for the turbo generator is thus 16.1%.

$$\text{power generated by steam}$$
$$= \text{electrical generation efficiency}$$
$$* \text{heating value of steam}$$
$$= 0.161 \times 17.6\ \text{Mw} = 2.93\ \text{MW}$$

Gas turbine combustion (assuming no turbine heat loss):

$3CO + 4H_2 + 3.5O_2 \rightarrow 3CO_2 + 4H_2O + 1500$ kWh [22]

$$400\frac{\text{ton}}{\text{day}} \times \frac{1500\ \text{kwh}}{\text{ton}} \times \frac{\text{day}}{24\text{h}} \cong 25.4\text{MW}$$

With 50% of thermal efficiency from the gas turbine, the electricity generated is:

$$\text{power generated by turbine}$$
$$= \text{turbine efficiency} * \text{heating value of syngas}$$
$$= 0.5 \times 25.4\ \text{Mw} = 12.7\ \text{MW}$$

a) Required energy for industrial grade oxygen

For such a process, both industrial grade oxygen and electricity to power the torches have to be provided. The production of one ton of industrial oxygen requires about 250 kWh of electricity. The equation of gasification shows that one mole of combustible waste requires 3 moles of oxygen.

On the basis of the respective molecular weights, we find that for 148 kg of $C_6H_{10}O_4$, we need 3 x 32 = 96 kg of oxygen.

For 1 ton 390 kg of oxygen are required.

Therefore, the electricity needed to gasify one ton of MSW is 97 kWh of electricity per ton of MSW processed and must be provided by the electricity generated using the syngas.

Total required electricity

$$400\,\frac{\text{ton}}{\text{day}} \times \frac{97\ \text{kwh}}{\text{ton}} \times \frac{\text{day}}{24\text{h}} \cong 1.6\ \text{MW}$$

b) Required torche energy

For one ton, in one hour, energy of 115. KWh are required

$$400\,\frac{\text{ton}}{\text{day}} \times \frac{115\ \text{kwh}}{\text{ton}} \times \frac{\text{day}}{24\text{h}} \cong 2\ \text{MW}$$

c) Total net electricity produced by gasification

Total net electricity produced by gasification =12.7MW+2.9 MW – 1.6MW –2MW

= 12 MW

2.5 Carbon dioxide emissions calculations

2.5.1. Incineration process

The chemical reaction for complete combustion is:

$C_6H_{10}O_4 + 6.5O_2 = 6CO_2 + 5H_2O$ + 2800 kWh per ton of MSW

From equation of reaction 1mole of SW produces 6 moles of CO2 so that 146 kg of solid waste produce 264 kg of carbon dioxide the amount of carbon dioxide results from combustion of 400 t/d of solid waste which contains 60% organic component is equal to:

$$400\,\frac{\text{ton}}{\text{day}} \times \frac{\text{day}}{24\text{ hr}} \times \frac{1000\text{ kg}}{\text{ton}} \times 0.6 \times \frac{264\text{ kg}}{146\text{kg}} = 18.082\,\frac{\text{tons}}{\text{hr}}$$

$$= 18.082\,\frac{\text{t}}{\text{hr}} \times \frac{24\text{ hr}}{\text{day}} = 433.968\ \frac{\text{tons}}{\text{day}}$$

2.5.2. Gasification process

Gasification reaction by means of partial combustion with oxygen is:

$C_6H_{10}O_4 + 3O_2 \rightarrow 3CO + 3CO_2 + 4H_2 + H_2O$

The partial combustion of 1mole of SW produces 3 moles of CO_2 and 146 kg of SW produce 132 kg of CO_2 , CO_2produced by partial combustion of 400 t/d of solid waste which contains 60% organic component is equal to :

$$400\,\frac{\text{ton}}{\text{day}} \times \frac{\text{day}}{24\text{ h}} \times \frac{1000\text{ kg}}{\text{ton}} \times 0.6 \times \frac{132\text{ kg}}{146\text{kg}} = 9.041\,\frac{\text{tons}}{\text{h}}$$

$$= 216.984\,\frac{\text{tons}}{\text{day}}$$

3. Results and discussion

3.1. Evaluating the MSW heating value.

The average energy content of the different MSW fractions of Tripoli MSW was obtained from the Public Services Company and are shown in the following table 3.Table 3.shows that plastics have the highest energy content per kg among all other MSW categories. Textile has second most energy content. From Table 3 it can be seen that Metal and glass have no energy content. These energy content values are almost analogous to that of other global MSW [5].

Table 3.Energy content of MSW components

Component	Energy content (kJ/Kg)
Organic material	5500
Plastic	33800
Paper and cardboard	15800
Metal	0
Textile	18700
Wood	15000
Glass	0
Miscellaneous	5000

Thus the results show that the average HV of Zawia MSW is 10293.1kJ/kg. The minimum LHV required for the waste to combust without the addition of other fuel is 7000 kJ/kg MSW.[5] Generally, for waste incineration plants , a practical gross energy content in municipal waste, in kJ/kg, can range from 8000 kJ/kg MSW to 13000 kJ/kg MSW[22]. Figure 1.shows the heating values of different fuels including MSW.

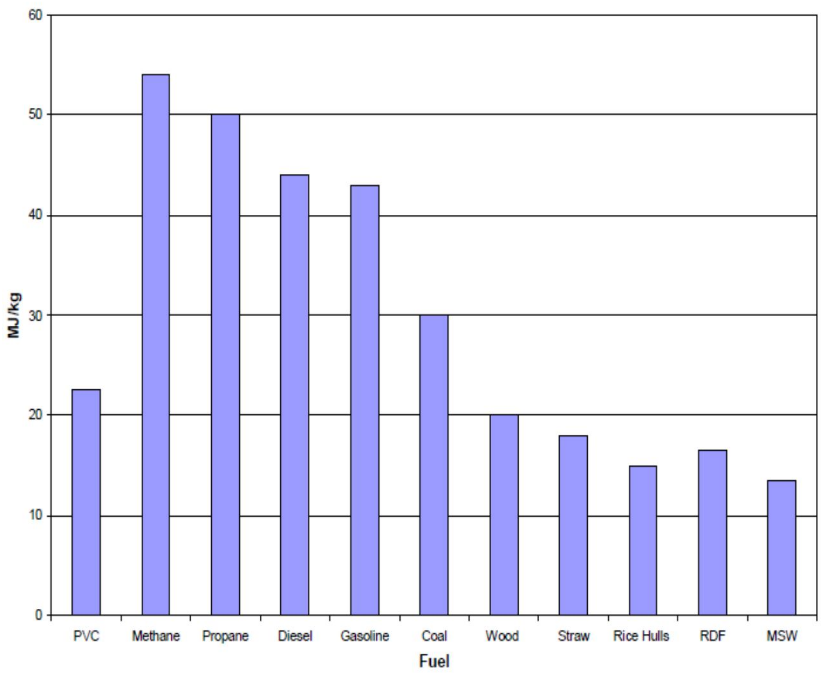

Figure 1.the heating value of different fuels. [6]

3.2 Energy Generation

Figure 2.shows the difference in the produced electricity between technologies. From the Figure it is apparent that gasification produces electricity (12MW) more than incineration produces (6.12MW). This is due to that the syngas has much efficiency when it is used directly in producing Electricity.

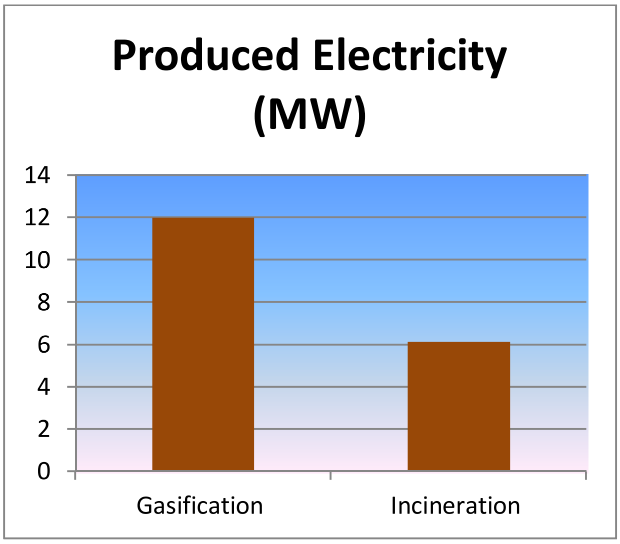

Figure 2.Produced Electricity (MW) by Gasification and Incineration

3.3 Carbon dioxide emissions

The incineration and gasification of municipal waste involves the generation of climate-relevant emissions. These are mainly emissions of CO_2. Figure 3 shows the gasification produces 9.041 tons/hr (216.984 tons/day) ofCO_2 emission which is half the CO_2 emission from incineration which produces18.08 tons/hr. (433.968tons/day).

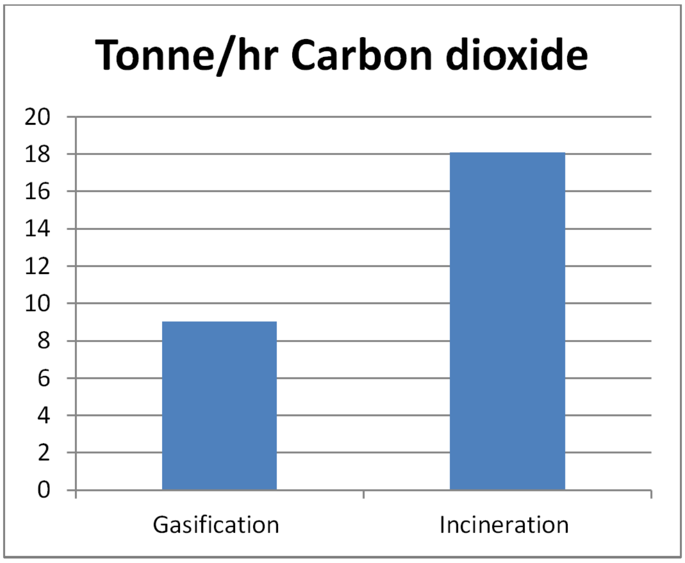

Figure 3.Carbon Dioxide emissions (Ton/hr) by Gasification and Incineration

4. Conclusion:

This paper presents an overview on municipal solid waste (MSW) that can be used as a source of energy in city of Zawia -Libya. The technical feasibility and environmental impacts of different (MSW) management systems (namely gasification and incineration technologies) for implement were studied. The type, amount, and energy content of MSW in Zawia city were estimated. The total daily MSW generation in Zawia municipality is found to be about 400 tons per day. Results show that among the MSW, organic matter is the higher portion of MSW which accounted for 52.8%. Results also show that the average HV of Zawia MSW is 10293kJ/kg. Finally it's found that gasification produces more Electricity and less greenhouse gas emission than Incineration. The production of Electricity from MSW will reduce the Libya dependence on fossil fuels, which will reduce both pollution and greenhouse gas emissions.

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