THE TECHNICAL AND ECONOMIC FEASIBILITY OF INCINERATION AND GASIFICATION OF ZAWIA′S MUNICIPAL SOLID WASTE (MSW) TO PRODUCE ELECTRICITY (SEC-35)

AlaaAlgharabli

University of Zawia, Facility of Engineering, Zawia, Libya

Alaa.algharably@gmail.com

ABSTRACT

This research is an accomplishment of a previous paper published in University Bulletin[1]. It demonstrates a general understating for different municipal solid waste (MSW) systems (waste to energy systems), which are recognized as a renewable source of energy that could be implemented in ZawiaCity-Libya The focus was on two popular methods of MSW systems which are incineration and gasification. 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 analyzed. 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 which is equal to the third of Zawia City needs of Electricity while Incineration produces 6.14 MW.In addition,the economic feasibility of both technologies was put into consideration. The total cost for the treating amount of MSW using the incineration was found to be 3216850L.D which is 25% less than the cost of gasification which was4021063 L.D. Also, the gasification exhibits more profitability than the incineration process with 1792308 LD/year.

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

1. 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. [2345678910]

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.[111213141516]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 economic 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

By identifying the daily productivity of Zawia city of solid waste and its enthalpy, it was possible to calculate the amount of energy obtained from the waste, which in turn is a source of income for the city. It was achieved in the following steps:

2.1. The daily MSW production rate in Zawia city

Due to the lack of date the daily production rate of Zawia City was estimated based on a
study conducted by Tripoli Public Service Company (TPSC) it considered 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 is400 tons per day.[1]

2.2. The composition of MSW in Zawia city

The composition is the main indicator of how much energy can be obtained out of waste. The composition of MSW is directly controlled by the population growth, lifestyle and the economic state of any community. In general, the composition of MSW in Libya consists of six major categories of waste: organic matter, paper–cardboard, plastics, glass, metals, and miscellaneous.[1]
The hydrocarbon formula C6H10O4 most closely approximated the mix of organic wastes in MSW. Therefore, in this study MSW was approximated by the formula: C6H10O4 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.[1]

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 the maximum fraction of the MSW with percentage of 52.8% 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.[1]

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

2.3The total heating value of Zawia MSW

The total 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.

2.4Energy balance

In order to estimate the power generated by both methods it was required to make an energy balance over the processes. The next two sections give an effective explanation for the energy balance steps.

2.4.1Incineration 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.[1]

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% [1]

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

$\text{heating value of steam} = \text{combustionefficiency} * \text{heating value of MSW}$[1]

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

Production rate of steam = heating value of steam /Enthalpy[1]

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

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

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

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

$= 6.14\text{MW} \times 365\frac{day}{year} \times 24\frac{hr}{day} = 53786\ \text{MWh/year}$

2.4.2Gasification 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 [19]

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

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

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

Power generated by steam = electrical generation efficiency * heating value of steam = 0.161 ×17.6 Mw = 2.93 MW

Gas turbine combustion (assuming no turbine heat loss):

$3CO + 4H_2 + 3.5O_2 \rightarrow 3CO_2 + 4H_2O + 1500$ kWh [19]

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

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

Power generated by turbine = turbine efficiency*heating value of syngas = 0.5 ×25.4 Mw = 12.7 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+2.9MW–1.6MW–2MW =12MW

2.5 Cost estimation

In this section we will calculate the total cost, revenue, the profit and the bay back for both incineration and gasification plants.

2.5.1 Incineration cost estimation

In our calculations We use the factors methods presented inChemical Engineering Design Principles, Practice and Economics of Plant and Process Design hand book which associated with the following assumptions

- **Assumptions**

1. According to suppliers and manufacturers the average cost for incineration equipment that made from carbon steel with capacity of 400 t/d and life time (5-8 years) is 700000 L.D

2.Waste input to incinerator = 80% of the total waste.

3. Depreciation rate = 5%

4. Electricity (average price =0.5L.D/kw)also the average price for metal scrap equal to 150L.D/ton where the plasticwaste price equals to 250 L.D/ton.[20]

5. The yearly operational cost of the incineration plant includes utility costs, human resource costs, cost of chemical materials needed for air pollution control, cost of auxiliary fuel when needed, cost of materials for amenity and office maintenance, and other administrative costs, excluding equipment maintenance cost equal to 33 L.D for 6MW of electricity.

6. The average population growth (for the last 30 years) equal to 0.93% .[21]

7.The plant is being operated in three shifts and 5 men work per shift to produce 6 Mw of electricity the cost of labor is 1800L.D/day.

1-Total capital cost

If we use the equation:

$$C = \sum_{i=1}^{i=M} C_{e,i,CS}\left[(1 + f_P)f_m + (f_{er} + f_{el} + f_i + f_c + f_s + f_l)\right]$$

Where:

$C_{e,i,cs}$= purchased equipment cost of equipment i in carbon steel;

M = total number of pieces of equipment;

f_p= installation factor for piping = 0.2

fm= material factor =1

f_{er}= installation factor for equipment erection = 0.6

f_{el}= installation factor for electrical work = 0.15

f_i= installation factor for instrumentation and process control = 0.2

f_c= installation factor for civil engineering work = 0.2

f_s = installation factor for structures and buildings = 0.1

f_l = installation factor for lagging, insulation, or paint = 0.05
The total installed ISBL cost of the plant is then
C =700000[(1+ 0.2) +(0.6+0.15 + 0.2 + 0.2 +0.1 +0.05)] C = 1750000 L.D
Offsites (OS) = 0.4* $C_{e, i, cs}$ = 280000L.D
DE= Design and Engineering = 0.2
X= Contingency = 0.1
Total fixed capital cost C_{FC} = C(1+OS) (1+DE+X)
C_{FC} = 3185000L.D
Working capital cost= 0.01* C_{FC} =31850L.D
Total capital cost =3216850L.D

2- Total Production Cost (TPC)

a) **Variable costs**

Utilities costs**:** (water, gas, raw materials, electricity)=33*365**=12045 L.D/year**

b) **Fixed costs:**

1- . Maintenance costs

Maintenance costs= 3% of ISBL =525000L.D/year

2- Labor Position or men/shift

Labor Position = $3600\ {}^{L.D}/_{month.men} \times 5men \times 12month$ =216000 L.D/year
Total Labor cost= 648000L.D/year

3-Supervision costs

Supervision = 25% of labor = 162000l.D/year

4-Direct overhead costs

Direct overhead = 45% of (Labor + supervision) = 364500L.D/year

5-Plant overhead costs

Plant overhead = 65% (Labor + Maintenance)=1699500L.D/year

6-Insurance costs

Insurance = 2% of C_{FC} = 63700L.D/year

7- Depreciation

Depreciation = 5% C_{FC} =159250 L.D/year

Total production cost =1+2+3+4+5+6+7+8=3633995 L.D/year

3- Incineration revenue

Electricity revenue = 0.5 L. D*50000KW/day*365day/year= L.D/year 1095000
Based on the weight percentage of metals and plastics in the MSW the metals and plastics revenue were:
Metals (Aluminium &steel revenue)= 0.058*0.8*400ton/day*250L.D/ton*365day/year=1693600 L.D/year
Plastic revenue=0.124*0.8*400ton/day*150L.D/ton *365day/year=

= 2172480L.D/year

Total Revenue=4961080 **L.D/year**

4- Incineration profit

Gross profit = Revenue - Total production cost
Gross profit =1327085 L.D/year
Net profit = Gross profit –Tax
According to the Libyan tax law;Tax equals to 20% of Gross profit.
Tax =265417 L.D
Net profit = 1061668 L.D/year
Pay back = Total capital cost / Revenue
The payback will be within 7 months depending on the revenue amount.

2.6.2 Gasification process cost estimation

The gasification investment cost will be calculated by applying a factor (f) on the capital cost of incineration (COI). Below, the formula is used to calculate the capital cost of gasification (CCOG):

$$CCOG = CCOI * f\ (CC)$$

The factor for capital cost was chosen between 1.0-1.5, the capital cost can be lower if the technology used is matured. [26]

CCOG=3216850 * 1.25= 4021063L.D

$$COG(O\&M) = COI(O\&M) * f\ (O\&M)$$

The factor chosen here is between 1.0-1.1.[22]

COG(O&M) = 3633995*1. 05=3815695L.D/year

As the production of electricity from Gasification equal to 12MW/day; The revenue from Electricity will be double of that from incineration, and it equal to 2190000L.D/year, while the revenue from metals, plastics and charge fee is the same as in incineration.
The total Gasification process revenue is equal to 6056080 L.D /year.
Gross profit=2240385 L.D/year
Tax=448077 L.D/year
Net profit = 1792308 L.D/year
The payback will be within 7 months.

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. 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.[19]

3.2 Energy Generation

Figure 1. represents the difference in the electricity productivity between technologies. From the Figure it is clear 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.

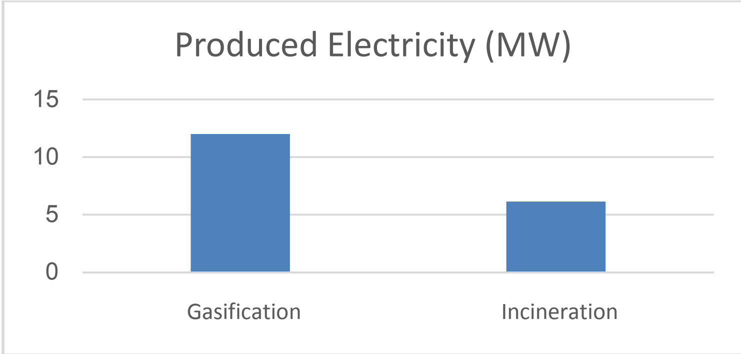

Figure 1.Produced Electricity (MW) by Gasification and Incineration.[1]

3.3 Cost estimation

Tables (4) and (5) explain the calculations for the first year. Table (4) illustrates the total quantity of waste collected each year. It also shows the quantity incinerated each year.

Table (4) waste generated and incinerated

Population	250000	person
Average waste per person	1.6	Kg/ day
Total waste	146000	ton/year
Waste incinerated (80% of the total waste)	116800	ton/year
Incineration facility		
Total lines	1	Line
Capacity (per line)	400	ton/day
Energy generated	360	kWh/ton

Table (5) shows the first year total revenue capital and operation costs. The total revenue equals to the summation of electricity fee and the revenue of metals and plastics.

Table (5) The Expenses and Income from Incineration and Gasification

Description	Incineration	Gasification
Total capital cost L.D	3216850	4021063
Total production cost L.D/year	3633995	3815695
Profit	1061668	1792308

L.D/year		
Revenue L.D/year	4961080	6056080

It can be seen from the table (6), the capital cost of gasification costs more since it is a new technology and more complex equipment in case of gasifier is needed. It has been assumed for gasification that the capital cost is 1.25 times higher than for the incinerationtechnology due to the gas turbine. In the case of the O&M cost it has assumed to be 1.05 of that for incineration. They are new technologies therefore they will need more supervision.Although the both plants may recover the capital cost at the same period of time the profit of Gasification process is higher. Gasification is more profitable to invest in in this case.

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 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 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.

From economic side of view, the gasification plant has more feasibility and it can be considered to be a new income resource for Zawia municipality.

5- References

[1]**Dr. Omar sultan, Dr. Osama Bshena, AlaaGrabli, RedaFhelboom, Comparative Analysis of Incineration and Gasification of Zawia′S Municipal Solid Waste (Msw) to Produce Electricity, University Bulletin, ISSUE No.21- Vol. (1) – January – 2019.**

[2]ZainTadros; susceptibility of underground water pollution in the surrounding area of the landfill site Rusaifa solid waste; 2002

[3]www.osgc.net/pdf/technology_flyer.pdf

[4]Department for Environment Food & Rural Affairs; Incineration of municipal solid waste; 2013.

[5]http://www.jeag.com/home/home.html

[6]Alexander Klein; Gasification: An Alternative Process for Energy Recovery and Disposal of Municipal Solid Wastes; 2002.

[7]M. Sawalem, E. Selic, J.-D. Herbell. (2008), J.-D. Herbell, *Hospital waste management in Libya: A case study*, Department of Mechanical Engineering, Waste Management Engineering, University of Duisburg-Essen, Bismarckstr. Duisburg, NRW, Germany, Available at:goo.gl/lxuKrR[Accessed 21 December. 2018].

[8]Natali Ganfer; recovering energy from waste; 2011.

[9]https://ar.wikipedia.org/wiki/%D8%A7%D9%84%D8%B2%D8%A7%D9%88%D9%8A%D8%A9_(%D9%84%D9%8A%D8%A8%D9%8A%D8%A7).

[10]www.bridgewater-nh.com

[11]U. Campos, H. Zamenian, D. Koo, D.W. Goodman; International Journal of Emerging Technology and Advanced Engineering, Volume 5, (2), 2015.

[12]T. Pradhan, S. Rai; International Journal on Recent and Innovation Trends in Computing and Communication, Volume,5 (10), 2017.

[13]Thermochemical Waste Conversion Technologies. Brisbane, Australia: CSIRO; 2014. csiro: EP146713.

[14]Farhan Masood; Solid Wastes Use as an Alternate Energy Source in Pakistan; 2013

[15]R. B. Williams; B. M. Jenkins; D. Nguyen; Solid Waste Conversion: A review and database of current and emerging technologies; 2003

[16]Bary Wilson; Comparative Assessment of Gasification and Incineration in Integrated Waste Management Systems; EnviroPower Renewable Inc. report 2008.

[17]M. Elmnifi, M. Amhamed, N. Abdelwanis, O. Imrayed; Environment & Ecosystem Science, 2 (1) 2018.

[18]Etriki. Jalal, May, 2013, Municipal solid waste management and institutions in Tripoli, Libya: applying the Environmentally Sound Technologies (ESTs) concept, THE UNIVERSITY OF HULL, The UK.

[19]Caroline Ducharme; Technical and economic analysis of Plasma-assisted Waste-to-Energy processes; 2010.

[20]Ibrahim Badi , Mohamed Sawalem, Ali Shetwan, Feasibility Study Of Waste Incineration Plant In The City Of Misurata - Libya , In.J. of Engineering Sciences & Research Technology, Vol.5, No.2, pp. 153-159, February. 2016.

[21]http://www.tradingeconomics.com/libya/population- growth-annual-percent-wb-data.html [accessed February 2019].

[22]Mahdi Al Naami ; Thermal Conversion of MSW a Comparison of the System Performance:DirectCombustion Versus Conversion Through Syngas in CHP Plant,2015.