INVESTIGATION OF ENERGY RECOVERY FROM MUNICIPAL SOLID WASTE: A CASE STUDY OF AL-KARAK CITY / JORDAN

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Abstract

Municipal solid waste (MSW) from Al-Karak city is monitored and characterized. The MSW is sorted into 14 different waste categories. In addition, the MSW is separated into several size fractions, followed by sorting and characterization. The average daily production rate of waste is 61.5 ton/day. The MSW generated per capita is estimated to be 0.55 kg/capita/day. The main input MSW comprised a modest proportion of organic content 38.8 %. Other combustible fractions are present in significant proportions, allowing the waste to be utilized for energy recovery. Refuse-derived fuels (RDFs) may be made from waste fractions > 100 mm and 50 - 100 mm.

Keywords:

Municipal solid waste;
Waste screening;
Waste characterization;
Physico-chemical properties;
RDF.

1 Introduction

Jordan is witnessing a steady increase in the amount of waste due to the large population growth, the influx of refugees, and economic, commercial and agricultural expansion. The amount of municipal solid waste (MSW) increased from 2.077 million tons/yr in 2014 to 3.466 million tons/yr in 2018 [1, 2]. The increasing amount of solid waste (SW) imposes a burden on the infrastructure administrated by the municipalities and the joint service councils and increases the financial costs allocated to dealing with the collection and transportation of SW [3].

Proper management of SW necessitates monitoring and quantifying the daily generation rate of the waste and identifying carefully its sources. In addition, the various waste components and their percentages must be identified. The availability of such data will help decision-makers in the municipalities to develop appropriate plans for optimal handling of waste in a way that ensures sustainability, preserves the environment, and reduces the financial costs of the waste management process.

Instead of disposing of waste to landfills, which most of them lack proper engineering and sanitary design, other options can be more beneficial through separating part of the waste and utilizing that for reuse, recycle or recovery of materials or energy [3].

Jordan relies greatly on imported fossil fuels to meet its energy needs, which constitutes a great burden on the national economy. Therefore, Jordan is moving towards relying on a mixture of energy sources to ensure a state of economic stability and to ensure energy security. Using waste as a source of energy will contribute to achieving these strategic goals and contribute to mitigating the problem of dealing with waste. In fact, the government of Jordan is planning to raise renewable energy contribution in total energy mix. Energy generation in a range of 30-50MW is expected to be produced from biomass recourses [4].

Energy can be recovered from waste through biological conversion methods such as fermentation and anaerobic digestion processes [5-8]. Energy can be also recovered from waste through thermal conversion methods such as pyrolysis [9], gasification [10, 11] and incineration.

MSW is characterized by the presence of high percentage of organic matter and the consequent increase in water content, thereby, making direct burning of MSW ineffective. If the mixed MSW is screened, a fraction with high heat content can be obtained that can be used in various thermal processes. Refuse-derived fuel (RDF) is a reclaimed solid fuel that can be used as a substitute for traditional fossil fuels in industry such as in the cement production industry or combined heat and power plants [12]. The remaining parts of the screening process contain a high percentage of organic matter, which can be subjected to anaerobic digestion to produce biogas.

In Jordan, the feasibility of MSW utilization based on their composition, water content, and particle size fractions, has not been investigated adequately. Therefore, it is essential to undertake studies which involve the collection of informative data on waste composition that is hauled to disposal sites, which could provide information to national waste management authorities for decision making; hence, eliminate the confusion in the minds of investors who may want to do business or services in the waste management sector.

The aim of the present study is to generate a comprehensive data on the MSW composition based on its particle size fractions for use in planning and implementation of relevant waste management technologies in Jordan.

2 Materials and methods

2.1 Study area

Al-Karak Governorate is located in the south region of Jordan, about 140 kilometers to the south of Amman. It is divided into 10 municipalities, which vary between urban, rural and commercial districts. According to the Jordan National Census, the population of the Al-Karak Governorate in 2019 was 350000 [13]. The population of municipalities according to census results is given in Table 1.

Table 1: The population of districts according to census results 2019.

District	Population
Greater Karak	112060
Ayy	9010
Mutah and Mazar	74352
Sheehan	23820
Talal Aljadedah	8690
Abdulah Bin Ruaha	18580
Mu'ab Aljadedah	30798
Aghwar Janoobiyah	60650
Qatraneh	7812
El-Soltani	4228
Governorate total	350000

As in other Jordanian cities, the municipalities and Joint Services Council in Al-Karak are daily responsible for municipal cleaning, collection of waste, disposal of waste generated from households and markets and the management of the landfill. There is one landfill in Al-Karak Governorate (Al-lajoun landfill).

The study area was restricted to the Greater Karak Municipality (GKM), Fig. 1, where the municipal solid waste is collected from 15 districts. These districts are: Zaid Bin Al-Harithah, Al-Karak, Wadi Al-Karak, Al-Hiwayah and Al-Talajah, Al-Marj, Zahhoom, Al-Jadidah, Al-Thanyah, Manshiat Abu Hammour, Adr, Al-Shihabiyah, Al-Waysiyyah and Rakin, Al-Ghwair, Batir, and Al-Adnaniyah.

Fig. 1: Study area.

2.2 MSW monitoring and quantification

Al-Lajjoun landfill was monitored over three days with the assistance of staffs from the Joint Services Council and the GKM. At first, all trucks carrying the MSW from the 15 districts in GKM were weighed before and after unloading the waste by means of a weighbridge truck scale. In each day, the MSW from the 15 districts are unloaded in a special area assigned by the Joint Services Council to avoid mixing the waste with MSW coming from other municipalities. The waste bags were manually opened and shredded by knives then a loader thoroughly mixed all the waste. The multi quartering and coning procedure is used to produce a representative MSW sample for each day. Since completely mixing the contents with the loader, the collected waste is divided into successive quarters. After that, the samples are coned and quartered several times until they are around 1 % of the original waste amount. Fig. 2 show the steps followed during piling, mixing and quartering the waste.

Fig. 2: Monitoring of MSW at Al-lajjoun landfill.

2.3 MSW screening and sorting

The representative waste sample "main input MSW" was screened by an electro-mechanical screening unit. This unit has three different sizes (square opening) that can categorize the waste based on the size in the form of fraction of:

- more than 100 mm,
- between 50 mm and 100 mm,
- between 10 mm and 50 mm,
- less than 10 mm.

Fig. 3 shows the adopted methodology in screening the MSW samples.

Fig. 3: The adopted methodology.

The waste on each fraction was weighted by electronic balance. Each waste fraction was placed on a clean area, and then sorted manually into 14 categories by seven persons. Table 2 shows the sorting fractions identified in this study and examples of waste for each fraction.

The organic fraction consists of waste such as food waste, garden waste, spoiled food, kitchen waste, etc. The other fraction comprised waste such as: plastic, paper, cardboard, glass, textile, hygienic products, metals, compound material, electronic goods, and others. Plastics were further classified into plastic films and 3D plastic. Metals were divided into ferrous and non-ferrous.

Table 2: Categories of waste.

No.	Sorting fractions	Examples
1	Organic waste	food waste, garden waste, agricultural waste, food, coffee and tea filters, kitchen waste
2	Paper	newspaper, magazine, office paper, computer paper,, writing paper, envelopes
3	Cardboard	carton, boxes
4	Glass	bottles, fruit and vegetables, jars for chocolate, drinking bottles, windows, composite glass
5	Textile	clothes, covers, curtains and handbags
6	Plastic film	plastic bags, nylon, freezer bags, labels packaging films
7	Plastic 3D	plastic buckets, bottles, containers, plastic shoes, water and soft drink bottles
8	Ferrous	tin cans and bi-metal cans, magnetic drink and food cans
9	Non-ferrous	non-magnetic drink and foods cans, other non-magnetic metals, Aluminum cans and foil
10	Hygienic products	tissue paper, sanitary pads, bandages
11	Compound material	any material contains two or more substance like shaving razors, belts, toys
12	Electronic goods	electrical and electronic items
13	Others	undefined material
14	Fines < 10 mm	screened materials (mainly organic)

2.4 MSW characterization

The main input waste, waste fraction > 100 mm, waste fraction 100 - 50 mm, and waste fraction 50 - 10 mm were subjected to physical and chemical characterization. At first, representative samples for each stream were carefully prepared following standard sampling procedure. Samples are

shredded into 10 mm size, then again shredded to 1 mm size to meet the needs of small-scale laboratory testing. The standard methods followed in the analysis of samples are summarized in Table 3. Each analysis is conducted three times [14], and the reported results in this study represent the average values.

Table 3: Standard test methods for analytics.

Analysis	Target	Unit	Method
Proximate analysis	Moisture content, <i>MC</i>	[%]	ASTM D5142
	Volatile matter, <i>VM</i>		
	Ash content, <i>AC</i>		
	Fixed carbon, <i>FC</i>		
Ultimate analysis	<i>C</i>	[%]	EN 15104:2011
	<i>S</i>		
	<i>H</i>		
	<i>O</i>		
	<i>N</i>		
	<i>Ash</i>		
Calorific value	<i>CV</i>	[MJ/kg]	DIN EN 51900-1 & 51900-2
Heavy metals content	<i>Cd</i>	[ppm]	ASTM D7112
	<i>As</i>		
	<i>Cr</i>		
	<i>Hg</i>		
	<i>Ni</i>		
	<i>Zn</i>		
Chlorine content	<i>Cl</i>	[%]	EN 15408

3 Results and discussion

3.1 MSW generation rate

Table 4 shows the daily quantities of MSW of Al-Karak districts that arrived to the Al-Lajjoun landfill in three days.

Table 4: MSW generation rate in GKM.

No.	District	27 Jan [ton]	28 Jan [ton]	29 Jan [ton]	Average
1	Zaid Bin Al-Harithaharea	6.000	4.700	2.900	4.533
2	Al-Karak area	4.440	11.840	5.500	7.260
3	Wadi Al-Karak area	3.000	3.780	3.200	3.327
4	Al-Hiwayah / Al-Talajah area	3.000	5.040	2.700	3.580
5	Al-Marj area	5.800	2.920	2.600	3.773
6	Zahhoom area	2.000	2.360	2.100	2.153
7	Al-Jadidah area	3.000	0.000	2.500	1.833
8	Al-Thanya area	4.100	6.240	9.860	6.733
9	Manshiat Abu Hammour	5.000	6.520	6.200	5.907
10	Adr area	3.200	3.560	2.300	3.020
11	Al-Shihabiyah area	2.700	4.400	2.300	3.133
13	Al-Waysiyyah-Rakin area	4.600	6.660	6.400	5.887
13	Al-Ghwair area	4.400	0.000	4.100	2.833
14	Batir area	3.100	2.800	0.000	1.967
15	Al-Adnaniyah area	8.000	0.000	8.680	5.560
	Total	62.340	60.820	61.340	61.500

The average daily production rate of waste in GKM is 61.50 ton/day. The average daily production rate of MSW in Al-Karak Governorate is 308 ton/day [2]. Therefore, the GKM contributes approximately 20 % of the total MSW that sent to Al-Lajoun landfill.

The MSW generated per capita in GKM is estimated to be 0.55 kg/capita/day (based on a population of 112060 and waste generation of 61.50 ton/day). This value is lower than the value reported for the Al-Karak Governorate which is 0.88 kg/capita/day. Fig. 4 shows waste distribution among districts in GKM.

Fig. 4: Waste distribution among districts in GKM.

The highest portion is generated within the Al-Karak area 11.8 %. Al-Karak area is considered the city center with a population of 35613 [13]. The area comprises urban and rural areas, hospitals, and the main markets. On the other hand, Al-Jadidah area contributed the lowest percentage of waste share 3.0 %. Al-Jadidah area is considered a rural area, and the waste is collected every two days.

3.2 Main input MSW fractions

Waste characterization was based on the “Methodology for the Analysis of Solid Waste” of the European Commission (European Commission, 2004). The main fresh input MSW was sorted manually into 14 waste categories, Table 5.

Table 5: Main input MSW fractions.

No.	Waste category	Fraction wt [%]
1	Organic waste	25.2
2	Paper	3.8
3	Cardboard	10.8
4	Glass	1.1
5	Textile	4.5
6	Plastic film	12.4
7	Plastic 3D	6.3
8	Ferrous	1.9
9	Non-ferrous	2.7
10	Hygienic products	15.5
11	Compound material	0.9
12	Electric products	0.6
13	Others	0.7
14	Fines < 10 mm	13.6

The results showed that the main input MSW is strongly dominated by organic fraction. Accordingly, the total organic fraction in the MSW is 38.8 %, which is lower than the organic fraction reported for MSW in other Jordanian cities. For example, Hemidat et al. [12] reported 55.1 % organic fraction in the MSW from Amman city. Younes et al. [15] reported 48.9 % organic fraction in the MSW from Zarqa city. Batareseh et al. [16] reported 55.5 % organic fraction in the MSW from Aqaba city. The low organic fraction in MSW from the GKM might be attributed to source-separation of this waste fraction from the other waste fractions. People in the GKM utilize the organic fraction of MSW for animal and poultry foddering especially spent vegetables, fruit and bread.

The other main MSW fractions in the GKM are plastics 16.7 %, hygienic products 15.5 %, and paper and cardboard 14.6 %. Higher fractions of paper and cardboard, and plastics are noticed in Al-Karak compared to Amman. The fractions of paper and cardboard, and plastics in Amman city are 11 and 9 % respectively. The high percentage of these waste fractions in Al-Karak compared to Amman might be attributed to limited availability of recycling centers for these fractions in Al-Karak. In addition, these waste fractions are picked up in different districts in Amman by informal sector prior to collection and disposal to landfills. In the GKM, there is one factory for recycling paper and cardboard, which located in the Al-Hiwayah area.

From the sorting analysis it was assumed that about 80 % of the fine fraction < 10 mm was organic material.

3.3 MSW size distribution

A screen unit was used to identify the size distribution of the fresh MSW, Table 6. In addition, waste composition for each size fraction was identified.

Table 6: MSW size distribution and waste composition for each size fraction.

No.	Waste category	Percentage			
		> 100 mm	50 - 100 mm	10 - 50 mm	< 10 mm
1	Organic waste	2.9 %	18.6 %	80.2 %	100.0 %
2	Paper	10.0 %	1.5 %	0.5 %	0.0 %
3	Cardboard	23.3 %	9.7 %	1.8 %	0.0 %
4	Glass	0.0 %	2.6 %	1.1 %	0.0 %
5	Textile	12.1 %	2.3 %	0.3 %	0.0 %
6	Plastic film	29.5 %	9.1 %	0.6 %	0.0 %
7	Plastic 3D	10.9 %	7.5 %	1.8 %	0.0 %
8	Ferrous	2.4 %	2.0 %	1.9 %	0.0 %
9	Non-ferrous	2.6 %	4.6 %	1.7 %	0.0 %
10	Hygienic products	3.5 %	38.4 %	9.6 %	0.0 %
11	Compound material	1.8 %	0.7 %	0.4 %	0.0 %
12	Electric products	1.1 %	0.8 %	0.0 %	0.0 %
13	Others	0.0 %	2.3 %	0.0 %	0.0 %
14	Fines < 10 mm	0.0 %	0.0 %	0.0 %	-
Percentage size distribution		31.6 %	32.0 %	22.8 %	13.6 %

The results revealed that 31.6 % of the MSW was characterized by a size larger than 100 mm, 32.0 % was characterized by a size in the range of 50 - 100 mm, 22.8 % was characterized by a size in the range of 10 - 50 mm, and 13.6 % was characterized by a size smaller than 10 mm. Many literatures classified MSW based on the size distribution of the waste. For instance, Hemidat et al. [12] screened MSW and found that approximately 30 % of the overall MSW screened could be retrieved as high fraction waste sizes > 100 and > 150 mm, while 10 % of the waste had sizes less than 10 mm. Sakri et al. [17] categorized the MSW samples into four groups based on particle size: > 100, 80 - 100, 60 - 80, and less than 60 mm. The majority of the input MSW, according to the researchers, was less than 60 mm, which accounted for about 43 % of the total MSW. The coarse fractions of 80 - 100 mm and > 100 mm made up 17 and 32 % of the overall input MSW respectively, while the medium fractions of 60 - 80 mm made up 8 %. The reported sizes in literature are different due to differences in

the objective of the screening step for the final-end-application of waste whether to be used for energy and material recovery (RDF, biogas, composting).

The waste fraction 10 - 50 mm comprised mainly of organic waste 80.2 %. Similarly, the fine waste fraction < 10 mm was dominated by organic constituents. It is proposed that these waste fractions to be utilized as main or co-substrate for biogas production via anaerobic digestion. On the other hand, the percentages of paper, cardboard, textile, plastic film, and plastic 3D in the waste fraction > 100 mm are the highest compared with other fractions. These waste categories enhance the calorific value of this fraction, thereby, making it suitable for RDF production. Ferrous and non-ferrous products are almost in the same range in all waste fractions. The total amount of metals was found in the range of 3.6 - 6.6 %. Waste fraction 50 - 100 mm comprised the highest percentage of hygienic products 38.4 %.

Reza et al. [18] reported potential RDF production from MSW for the years 2015 and 2020 at a yield of 52.8 and 39.9 % respectively for Metro Vancouver Waste Management. Gallardo et al. [19] produced RDF from MSW with a yield of 43.1 %. Hemidat et al. [12] reported a 39 % RDF yield obtained from screening MSW at a size > 80 mm. In this study, potential RDF production from screening MSW at size fractions > 80 mm and 50 - 100 mm can be achieved at yields 31.6 and 32 % respectively.

3.4 Physical and chemical characteristics of MSW and RDFs

Physico-chemical analysis was carried out for the MSW in the form of fractions of > 100 mm (RDF-1) and 50 - 100 mm (RDF-2). The heating value, proximate analysis, ultimate analysis, chlorine content and heavy metal concentrations are examined in order to identify the produced RDF's quality, Table 7.

The results of the proximate analysis indicate that the screening step has effectively reduced the moisture content of waste. The presence of high percentage of organic content in waste is expected to increase the moisture content. The main input MSW has low heating value 5.99 MJ/kg compared to 13.45 and 11.86 MJ/kg for RDF-1 and RDF-2 respectively. The low heating value of the main input MSW is attributed to the high organic fraction content. Kara et al. [20] reported that the heating value of RDF is 14.64 MJ/kg and 25 % moisture content. Hemidat et al. [12] produced RDF from MSW with heating value of 15.58 MJ/kg and 25.5 % moisture content.

Table 7: Proximate analysis and heating values of MSW and RDFs.

			Unit	Main input MSW	MSW > 100 mm RDF-1	MSW 50 - 100 mm RDF-2
Proximate analysis	Wet basis	MC	[%]	43.2	12.4	23.8
		VM	[%]	38.0	72.0	54.4
		AC	[%]	15.4	5.2	15.1
		FC	[%]	3.4	10.4	6.7
	Dry basis	VM	[%]	66.9	82.2	71.4
		AC	[%]	27.1	5.9	19.8
		FC	[%]	6.0	11.9	8.8
Heating value (HV)		HHV*	[MJ/kg]	7.39	23.75	19.55
		LHH**	[MJ/kg]	5.99	13.45	11.86
* Higher heating value, ** Lower heating value						

The ash content for the input MSW decreased from 27.1 to 5.9 and 19.8 for RDF-1 and RDF-2 respectively. Zhao et al. [20] reported RDF with a range of ash content 6.3 and 12.5 %, whereas Sprenger [22] reported RDF with higher values of ash content 19 - 39 %.

The volatile matter content for the input MSW increased from 66.9 to 82.2 and 71.4 % for RDF-1 and RDF-2 respectively. Kara et al., [20] characterized RDF with volatile matter content around 81.60 %. Kimambo and Subramanian [23] characterized RDF with volatile matter content around 86 %.

The fixed carbon content for the input MSW increased from 6 to 11.9 and 8.8 % for RDF-1 and RDF-2 respectively. Kimambo and Subramanian [23] reported fixed carbon content for RDF in the range from 4.6 to 9.2 %. However, Azam et al. [24] reported fixed carbon content for MSW and RDF as 7.2 and 4.7 % respectively.

Due to the fact that the characteristic of RDF is greatly influenced by the ultimate analysis, the latter was carried out for the RDFs and the results compared with ultimate analysis of coal material, Table 8.

Table 8: Ultimate analysis and chlorine content of RDFs and coal (dry basis, wt [%]).

	RDF-1 (this study)	RDF-2 (this study)	RDF [24]	Coal [25]
<i>N</i>	0.64	0.80	0.81	1.26
<i>H</i>	8.40	6.70	8	5.50
<i>O</i>	21.80	24.80	34	31.48
<i>C</i>	57.50	47.50	58	58.02
<i>S</i>	0.07	0.15	0.1	0.21
<i>Chlorine</i>	0.39	0.31	0.49	

The ultimate analysis results indicate that the carbon content in RDF-1, 57.50 % is very close to the values reported for coal 58.02 %, while RDF-2 has relatively low carbon content 47.50 %. Elements that cause harmful gaseous emissions such as nitrogen and sulfur have lower content in both RDF-1 and RDF-2 compared to that for coal. These findings indicate that the produced RDFs are good substitutes for coal from environmental perspectives. The hydrogen content for RDF-1 and RDF-2 are 8.40 and 6.70 % respectively, which are slightly higher than those reported for coal. On the other hand, the oxygen content for both RDFs is smaller than that for coal. Infiesta et al. [25] reported an ultimate analysis for RDF produced from MSW with values that are close to those reported in this study.

Chlorine content in RDFs is an important quality indicator for the potential use of RDFs in waste-to-energy plants; it causes high-temperature corrosion and poor performance [27]. Prior to use, it is essential to investigate the chlorine content in the produced RDF in order to avoid expensive chlorine-related problems during utilization. Following the European Standard (EN 15408) for the determination of chlorine content in the produced RDFs, the average chlorine content for both RDF-1 and RDF-2 were 0.39 and 0.31 % respectively. It has been reported that the maximum acceptable limit for chlorine in RDF is 0.9 % [28]. Accordingly, the produced RDFs in this study possessed chlorine content within the acceptable limit.

In terms of heavy metal concentrations, RDFs from GKM showed a wide variety of heavy metal concentrations, as seen in Table 9. The heavy metal concentrations in RDFs produced at GKM are in accordance and sometimes lower than those values set by Europe's standard for RDFs [18]. Heavy metal concentrations are also smaller than those found in Amman city [12].

Table 9: Heavy metals concentration in the produced RDFs [mg/kg].

	Greater Karak Municipality [this study]		Amman [12]	Standard limits [18]
	RDF-1	RDF-2	RDF	
<i>As</i>	0.87	0.98	0.99	10
<i>Pb</i>	59	51	N/A	100
<i>Cd</i>	0.78	1.1	2.95	5
<i>Cr</i>	62	44	66.00	200
<i>Ni</i>	14	19	58.50	200
<i>Zn</i>	150	260	270	500
<i>Hg</i>	< 0.03	< 0.03	<0.03	1

4 Conclusions

The experimental research was conducted in Greater Al-Karak Municipality (GKM) in order to generate a comprehensive data on the MSW composition based on its fractions particle sizes for use in planning and implementation of relevant waste management technologies in Jordan.

The research work began by obtaining representative sample of mixed MSW generated from the city of Karak at Al-lajoun landfill. A screening unit was then used to categorize the input mixed waste according to its particle size in different fractions. Waste composition was identified based on the "Methodology for the Analysis of Solid Waste" of the European Commission. The MSW was

divided into 14 primary categories. Sampling and Laboratory analysis were carried out to identify physico-chemical properties. RDF quality was examined and compared with the values set by some European standards.

The results showed that 31.6 % of the MSW could be recovered as a large fraction > 100 mm, 32.0 %, 50 - 100 mm, 22.8 %, 10-50 mm, and 13.6 %, < 10 mm. Accordingly, there is high potential for utilizing of the waste fractions of sizes 50 - 100 mm in waste to energy applications (refuse-derived fuel (RDF)). While, for the large fraction > 100, the waste included 2.9 % organics, and about 85.0 % combustible material respectively, which are considered as RDF.

The calorific value of unprocessed MSW was found to be 6.00 MJ/Kg. The calorific value of the RDF produced from the pilot project ranged from 11.86 to 13.45 MJ/kg, which made it suitable as a fuel. The ash content of the RDF produced appeared to have a low range between 5.9 % and 19.8 %. Chlorine and heavy metals contents were found to be within the acceptable limits.

The experimental research in Al-Karak City proved that RDF from MSW could be a strategic component of an integrated waste management system in order to achieve the recycling and reduction targets for combustible materials going to landfill.

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