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Analysis of Refuse Derived Fuel Utilization from Aqaba Municipal Solid Waste

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ABSTRACT

Disposal of municipal solid waste (MSW) in landfills is still the most common MSW disposal practice worldwide. Although landfills are increasingly equipped with better liners and environmental protection systems, the threat of harm to the environment from landfills continues to be a problem in the long term, due to leachate and gas production. As an alternative to landfilling, a portion of the waste (mainly plastics, textile, cardboard and paper, wood and other organics) can be converted into Refuse Derived Fuel (RDF) and used as a fuel source rather than fossil fuel. An RDF facility can be developed as part of an integrated waste management system in Aqaba. This paper summarizes a recent study of the Aqaba MSW waste stream, explains relevant specifications and standards for RDF and proposes possible uses of RDF as fuel in cement industry.

KEYWORDS: Refuse derived fuel, Municipal solid waste, Environment protection.

INTRODUCTION

The waste characterization study summarized in this paper represents the first effort conducted in Jordan so far to quantify and carefully characterize waste in Aqaba. A team from both University of Central Florida (UCF) and Jordan University for Science and Technology (JUST) conducted a study on landfills in Jordan in 2001 (Chopra et al., 2001), which described the Aqaba landfill as an open dumpster with no landfill sequence plan, compacting or leveling, where covering takes place only occasionally. The previous study, however, used approximate default values for waste composition (w/w %) for all the landfills in Jordan (including Aqaba landfill) to model leachate generation rates.

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The results of the present study provide an accurate understanding of the generated waste stream in various sectors of the city of Aqaba, as well as clear picture of the waste composition delivered into the landfill.

This information will be useful in facing the primary challenge for Aqaba waste management of developing an integrated solid waste management plan, consisting of a properly engineered sanitary landfill and waste diversion mechanisms, including RDF, as considered in this paper.

Aqaba is a central industrial and tourist hub for Jordan and is home to the country's only port. Its population, currently at about 100,000, is increasing rapidly and the city is expanding as investments pour into the local economy. Aqaba city currently generates approximately 120 tons/day of MSW (Waste Characterization of the City of Aqaba, 2013). This MSW is disposed of in an unlined landfill 12 km south-southeast of Aqaba city at the base of the Aqaba mountains.

Converting waste into Refuse Derived Fuel (RDF) that can be used as a replacement to fossil fuels has environmental, economic and social benefits. RDF is heavily used in Europe, where management and production processes are strictly regulated.

Environmental benefits include the diversion of MSW from landfilling and consequent avoidance of long-term impacts of the landfilled waste on the surrounding environment. Furthermore, use of RDF as fuel replaces the burning of non-renewable fossil fuels, which contributes to greenhouse gases and global warming.

Economic benefits include savings in the costs of sanitary landfill cells and associated infrastructure, as less waste will be going to the landfill and savings will be achieved at cement factories, since RDF is less expensive than fossil fuels it replaces. Reducing energy costs at those factories can increase their profitability and competitiveness. Also, developing an RDF facility creates jobs and improves financial stability for the local community.

LITERATURE REVIEW

Onda Mechanical Biological Treatment (MBT) Plant

A study performed by Gallardo et al. (2014) found a similar waste characterization for Onda, Spain, where an MBT plant is used to recover recyclables (a summary of the composition of the waste at the facility entrance is: organics 57.1%, paper and cardboard 15.2%, plastics 10.1%, glass 7.1%, metal 3.8%, textile 3.5% and other constituents 3.2%). This similarity to the Aqaba city waste composition makes that study relevant to the Aqaba situation.

Onda MBT plant is for material recovery for recycling only and does not have RDF generation capacity. Galladro et al. (2004) obtained 12 samples of the reject fraction from the MBT plant over 14 days and experimented with the possibility of using the reject to generate RDF. This process of recovering valuable recyclables and then proceeding with RDF would be very similar to the process under discussion for Aqaba. The main conclusions of the Galladro et al. (2004) study are summarized as follows:

- The reject material from the MTB plant can be used to produce RDF, which can be used to produce energy.
- The produced RDF could be used in cement kilns and satisfies Spanish cement kiln standards.
- The chemical composition of the RDF satisfies the European Norm EN15359:2011, with the exception of Hg. This issue must be resolved before RDF can be used.
- Moisture content is one of the most important physical characteristics that affect the calorific value of the produced RDF, therefore affecting the feasibility of the process.

Similar issues can be possibly anticipated for the Aqaba situation as well.

Proposed RDF Facility in Aqaba

The production of fuel from MSW, to be used in industries that require burning of such fuels, is called RDF production. RDF can be produced in many shapes, densities and sizes and the heat content and level of purity can vary. Two main things determine the type of RDF that can be produced: the purity of the raw waste stream and the type of processing used at the RDF facility. MSW in its current state in Aqaba (that is, without processing into RDF) would have a relatively low heat content and a high level of impurities. An estimation of the heat content of the Aqaba waste in its current state, based on the waste characterization prepared in the WRECP study, is presented in Table 3. Such a low calorific value, as well as high moisture content (due to high content of food waste) and high level of impurities make this waste unsuitable for burning as is. An RDF facility should be used to improve the characteristics of the waste and convert it into RDF.

Typical RDF facilities use a series of mechanical and manual processes, including the following (Christensen et al., 2011; Chang et al., 1997):

- Bag opening and waste spreading. This is an essential first step, as it allows the consecutive processes to proceed.

- Magnetic separators. These separators usually involve an overhead magnetic system that attracts ferrous metals and conveys them to a bin away from the waste stream. Ferrous metals can be part of large and heavy parts, so that an effective magnetic separation system can be installed after a waste shredder. Alternatively, a magnetic separator can be installed both before and after a waste shredder.
- Eddy current separators. These separators apply an electromagnetic field, which allows the separation of non-ferrous metals, such as aluminum and copper.
- Manual sorting. Sorting personnel can be distributed around the waste-conveying belt and each person can be responsible for picking a certain type of material. Although it is a manual process, this is actually one of the most reliable ways of separating specific high-value products from the waste stream.
- Size reduction. This process is necessary to homogenize the waste and break down large particles, in order to allow further separation. A hammer mill is commonly used in RDF facilities.
- Air classification. This is also an essential process for RDF separation, to separate lower-density materials (paper, plastic and other dry organic materials), which are the main components of RDF.
- Screening. The most popular screens are trommel screens. These have proven to be effective and can be used for both initial and final screening.

Light and large particles that remain after all these processes have high calorific value and are therefore the high-value RDF.

RDF Specifications and Classes

To provide an unambiguous classification for RDF, that takes into account all the parameters mentioned above and that can be used by both RDF manufacturers and users, the European Standard EN 15359 (Solid Recovered Fuels (SRF) – Specifications and Classes) was created. Note that SRF is the same thing as RDF. This European classification system should be used for the Aqaba RDF facility, to create a common understanding between RDF makers and buyers. To conform with EN 15359 RDF, the makers (that is, the RDF facility operators) will need to comply with requirements for classification, compliance and specifications.

Classification

The classification of SRF (the same as RDF) shall be based on the following three main fuel characteristics.

- Mean value for net calorific value (NCV).
- Mean value for chlorine content (Cl).
- Median and 80^{th} percentile values for mercury content (Hg).

The classification shall be in classes of 1 to 5 and as shown in Table 4.

Compliance

To comply with the declared classification, an SRF producer shall obtain monthly data measurements of NCV, Cl and Hg over a full year of operation, during which a quality system should be implemented. All the 12 measurements for each of the parameters shall be within the 95% confidence interval limits. For the calculation of 95% confidence interval lower and upper limits, the following equation is used:

$$X = \bar{X} \pm 1.96 \cdot \frac{s}{\sqrt{n}}$$

where

X is the lower/upper limit of the 95% confidence interval of the arithmetic mean;

$\bar{X}$ is the arithmetic mean (based on all measurements);

1.96 is the functional characteristic of the normal distribution (for the 95% confidence interval);

s is the standard deviation (based on all measurements);

n is the number of measurements (here n=10).

Specifications

The produced SRF shall be specified in accordance with a list of obligatory properties and a list of voluntary properties. The properties that are obligatory to specify are:

- Class code: the classification as discussed above.
- Origin: where the waste came from and what type of waste it is.
- Particle form: what form the final SRF will be in, such as pellets, bales, chips,… and so on.
- Particle size: what the diameter of the SRF particles is.
- Ash content: to be specified on a dry basis.
- Moisture content: specified as received.
- Net calorific value: specified as received and on dry basis.
- Chemical properties: required elements are chlorine content and heavy metals (antimony, arsenic, cadmium, chromium, cobalt, copper, lead, manganese, mercury, nickel, thallium and vanadium).

In addition to the above properties for which specification is obligatory, an additional list of properties can be specified on a voluntary basis, including biomass content, composition, fuel preparation, physical properties and chemical properties.

Using RDF in Cement Industry

The process of cement manufacturing has high energy requirements, accounting for approximately 30% to 40 % of total cement production costs (Holcim, 2006). Traditionally, coal, petroleum coke, natural gas and oil are the primary sources of energy in cement plants. Recently, however, alternative fuels derived from waste materials, such as RDF, have been used to meet some of the energy needs. Internationally, major cement manufacturers are increasingly using more alternative fuels. In 2012, it was reported (ERFO, 2012) that worldwide, Heidelberg used 16%, Lafarge used 7.6%, Holcim used 9% and Cemex used 15.7% alternative fuel. It is possible to use RDF at several points in cement production. The most common uses are (Holcim, 2006) in the main burner of the rotary kiln, in secondary burners and in the precalciner.

MATERIALS AND METHODS

A waste characterization study of Aqaba city MSW was performed by the USAID Water Reuse and Environmental Conservation Project (WRECP).This study was performed in accordance with ASTM D5231-92, for determining the composition of unprocessed MSW. To obtain a representative assessment of the MSW composition, 24 waste samples were analyzed. These included 6 samples from the collection route for each of 4 of the major waste contributors: hotel areas, commercial areas, poor residential areas and rich residential areas.

City Clean is the company that collected MSW in Aqaba city at the time of the study. Randomly selected City Clean trucks from each route were directed to a designated sorting area and requested to discharge the load being carried (between 450 and 500 kg). Each sample was sorted into 20 types, based on ASTM D5231-92 (See Table 1). Empty storage containers were weighed and used for sorting each sample. Waste items (including composite materials and containers) were then separated and placed in their respective sorting containers. The sorting process continued until the maximum remaining particle size was less than 1.2 cm. Each storage container was then weighed, so that the mass of the sorted waste items could be ascertained and recorded.

Of the 24 samples, 8 were taken in fall 2013 and 16 in spring 2014, taking into account variations in waste composition during weekdays and weekends, in addition to seasonal variations in tourist activity.

Six samples were tested for each area and an average value for the composition percentage for every waste component was calculated and presented in Table 2. Also, the variation in contribution of each of the four areas to the overall waste stream was accounted for and assessed based on truck-route data. The data obtained from City Clean showed that 4-and 5-star hotels generate 9% of the total waste stream, commercial establishments 40%, non-affluent residential areas 33% and affluent residential areas 18%. These factors were then used to assign appropriate weights to each area and to calculate the overall weighted average composition of Aqaba's waste stream (Figure 1) using the following formula:

$T_i = 9\% \, a_i + 40\% \, b_i + 33\% \, c_i + 18\% \, d_i$

where

T_i : Overall weighted-average percentage of waste component *i* in Aqaba's waste stream.

a_i : Percentage of waste component *i* in 4- and 5- star hotels' waste stream.

b_i : Percentage of waste component *i* in commercial establishments' waste stream.

c_i : Percentage of waste component *i* in non-affluent residential areas' waste stream.

d_i : Percentage of waste component *i* in affluent residential areas' waste stream.

Table 1. Waste types analyzed in waste characterization study for Aqaba city

Waste Item			Description
Paper	1	Mixed paper	Office paper, computer paper, magazines, glossy paper, waxed paper and other paper not fitting the categories of newsprint and corrugated
	2	Newsprint	Newspaper
	3	Corrugated	Corrugated medium, corrugated boxes and brown (craft) paper (that is, corrugated) bags
Plastic	4	PET	Water and soft drink bottles
	5	HDPE	milk bottles, detergent bottles, oil bottles, toys, plastic bags
	6	Film	Plastic film
	7	Other	All other plastics
Organics	8	Yard waste	Branches, grass, leaves and other plant material
	9	Food waste	All food waste except bones
	10	Wood	Lumber, wood products, pallets and furniture
	11	Other organics	Textiles, rubber, leather and other burnable materials
Ferrous	12	Cans	Tin cans and bi-metal cans
	13	Other	Iron and steel
Aluminum	14	Cans	Aluminum cans
	15	Foil	Aluminum foil
	16	Other	Aluminum
Glass	17	Clear	Clear glass
	18	Brown	Brown glass
	19	Green	Green glass
	20	Other inorganics	Rock, sand, dirt, ceramics, plaster, non-ferrous non-aluminum metals (copper, brass,… etc.) and bones

Table 2. Waste sampling results

Contribution to the Overall Aqaba MSW Directed to the Landfill (%)		Hotels	Commercial	Residential – Poor	Residential - Medium/Rich	Weighted Average-Waste Composition of Overall Disposed Waste in Aqaba (%)
		9	40	33	18	
Waste Component		Waste Composition for Different Areas in Aqaba (%) (Values for each area are average of 6 samples)				
Paper	Mixed paper	18.9	3.4	3.7	6.9	5.5
	Newsprint	0.5	5.7	1.6	2.3	3.2
	Corrugated	1.2	11.0	2.4	2.2	5.7
Plastics	PET	3.0	7.1	2.6	2.5	4.4
	HDPE	3.4	5.7	7.6	6.9	6.3
	Film	0.1	1.3	0.1	0.5	0.7
	Other	2.4	5.3	4.4	3.4	4.4
Organics	Food waste	51.5	38.3	62.9	54.7	50.5
	Yard waste	0.2	0.0	0.0	0.2	0.1
	Wood	0.0	1.3	0.8	0.5	0.9
	Other Organics (Diapers, Textiles)	1.8	6.4	2.9	1.7	4.0
Ferrous	Cans	6.0	3.5	2.3	2.0	3.1
	Other	0.0	1.7	0.8	0.1	1.0
Aluminum	Cans	3.5	4.2	1.2	3.9	3.1
	Foil	0.3	0.0	0.0	0.8	0.2
	Other	0.0	0.0	0.0	0.0	0.0
Glass	Clear	3.9	2.8	4.1	5.1	3.7
	Brown	0.9	0.5	1.1	1.7	1.0
	Green	2.1	1.7	1.2	3.0	1.8
	Other Inorganics	0.3	0.0	0.2	1.5	0.4

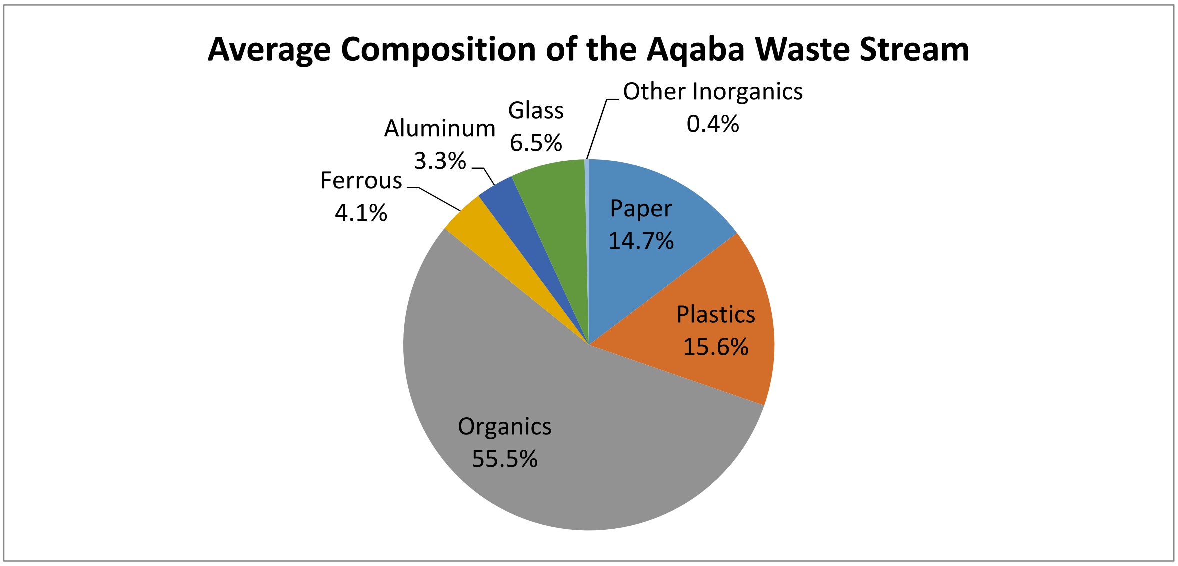

Figure (1): Average composition of municipal solid waste in Aqaba

Table 3. Estimated heat content of Aqaba waste

Type of waste	Percent	Million BTU/ton(1)	kJ/kg (2)	kJ/kg mixed waste
Mixed paper	5.6	6.7	7,792.1	433.1
Newsprint	3.3	16	18,608.0	605.2
Corrugated cardboard	5.7	16.5	19,189.5	1,093.3
PET	4.4	20.5	23,841.5	1,057.7
HDPE	6.3	38	44,194.0	2,804.2
Film	0.7	24.1	28,028.3	184.9
Other plastics	4.4	20.5	23,841.5	1,043.0
Food waste	50.5	5.2	6,047.6	3,056.6
Yard waste	0.1	6	6,978.0	6.0
Wood	0.9	10	11,630.0	101.3
Remaining portion	18.2	0	0	0.0
Total heat content (kJ/kg)				10,385.3

(1) Source of data: US Department of Energy (2007).
(2) Million BTU/ton = 1163 kJ/kg.

Table 4. SRF classification based on EN 15359

Classification Characteristic	Statistical measure	Unit	Classes 1	2	3	4	5
Net Calorific Value (NCV)	Mean	MJ/kg (ar)	≥25	≥20	≥15	≥10	≥3
Classification Characteristic	**Statistical measure**	**Unit**	**1**	**2**	**3**	**4**	**5**
Chlorine (Cl)	Mean	%(d)	≤0.2	≤0.6	≤1.0	≤1.5	≤3
Classification Characteristic	**Statistical measure**	**Unit**	**1**	**2**	**3**	**4**	**5**
Mercury (Hg)	Median	mg/MJ (ar)	≤0.02	≤0.03	≤0.08	≤0.15	≤0.5
	80th percentile	mg/MJ (ar)	≤0.04	≤0.06	≤0.16	≤0.30	≤1.0

RESULTS AND DISCUSSION

The study results indicate that organic wastes (predominately food waste) constitute more than half of the wastes generated in the city of Aqaba. Yard wastes, produced by agricultural or landscaping activities, are collected separately by Clean City and are sent to the Anqad Landfill in Aqaba, which is an old landfill that only receives demolition debris and green waste. Hence, yard waste had a negligible contribution to wastes being disposed of at the Aqaba landfill.

Plastics contributed roughly 16% by weight of the waste stream and were primarily composed of high-density polyethylene (HDPE) and, to a slightly lesser extent, polyethylene terephthalate (PET). Significant quantities of other forms of plastic materials (including film) were also present.

Paper wastes also constituted a major component of the waste stream; roughly 15%. Despite being collected separately from commercial areas by Clean City, significant amounts of corrugated paper were still being transported for disposal at the Aqaba landfill. Therefore, the amount of corrugated paper - typically used as freight packaging material - presented in this study cannot be assumed to be representative of the total amount generated in Aqaba, due to the absence of data that highlights the quantities successfully diverted from the landfill. Given Aqaba's role as Jordan's transport and shipping hub, the actual value of corrugated paper wastes may be significantly higher.

Aluminum, ferrous materials and glass wastes constituted roughly 3.3%, 4.1% and 6.5% of the waste stream, respectively. However, there was a noticeable increase in the waste stream's glass and aluminum content in the spring 2014 samples, as opposed to the fall 2013 samples. This increase could be attributed to a sharp increase in beverage consumption during warmer months, when domestic and international travel to Aqaba increases.

Based on the data obtained from the study of Clean City collection trucks, the average waste generation rate in the city of Aqaba was determined to be approximately 930 grams/capita/day, which falls within the range waste generation rates typical in other areas of Jordan (0.7-1 kg). This translates to a daily waste tonnage of roughly 110 tons/day, bearing in mind that the port and industrial regions south of Aqaba city also dispose of their wastes at the Aqaba landfill. Based on the daily truck route schedule, it was estimated that approximately 15 tons of solid waste are additionally generated from the industrial regions. This results in a collectively waste stream of 125 tons of municipal solid waste reaching the landfill daily. However, the composition of wastes generated from the port and industrial regions was not included in this study.

CONCLUSIONS

Converting MSW into RDF has several obvious environmental and economic benefits: reduction in the amount of fossil fuel used at cement plants, reduction in emissions from fossil fuel burning and avoidance of harmful impacts from waste landfilling. RDF production can be successful if the produced RDF is suitable for use in the market near the point of production. Mainly, this market is the cement industry; so, the product must be consistently at a specified calorific value, particle shape and size and level of chemical impurities.

An RDF facility needs high operational efficiency if it is to produce RDF at a reasonably low cost and to compete with other producers of alternative fuels. RDF facility operations require a special set of expertise that is often not available in the public sector; so, private sector participation will be important to the success of the RDF facility for the Aqaba landfill. This project will require access to finance, which is currently a challenge to the public entities in Aqaba that are responsible for solid waste management, which also can be resolved by involving the private sector.

The main challenges to developing an RDF facility in Aqaba are possibly the high content of wet organic waste, which should be dried to improve the heat content of the RDF, as well as the relatively small quantity of waste making the facility feasibility a concern.

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