

**Deanship of Graduate Studies
Al – Quds University**



**Investigating the Potential of Municipal Solid Waste
to Energy Opportunities in West Bank - Hebron City**

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Al – Quds University
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Thesis Approval

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to Energy Opportunities in West Bank - Hebron City**

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Dedication

To the candle that was burnt to light my road, to my wife Najwa, without whose caring support it would not have been possible, I dedicate this valuable work,

To my children Amal, Nada, Shatha and Ahmad who missed me often as I was busy setting up my experimental work,

To my parents who never stop supporting me since childhood, who have never failed to give me spiritual and moral support,

I dedicate this Work...

Declaration:

I certify that this thesis submitted for the degree of Master is the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not been submitted for a higher degree to any other University or Institution.

Signed:

Mohannad Abdullah Mohammad Nassar

Date: 27 / 9 / 2011

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Finally, I'm grateful to all my friends, and to every one who contributed to complete this study by their support and spiritual motivation ...

Abstract

This research focuses on identifying, quantitatively and qualitatively, the waste-to-energy potential by quantifying amount and composition of municipal solid waste generated in a densely urban area located in Hebron city. Samples are collected and used in accordance to American Society for Testing and Materials standard procedure at the laboratories of the Renewable Energy and Environment Research Unit of the Palestine Polytechnic University. Experimental studies are done on representative samples to identify its thermal properties (Gross and Net Calorific Values) in addition to proximate analysis (Moisture Content, Volatile Matter, Ash Content and Fixed Carbon) are carried out to identify the other relevant properties. Experimentally, identified properties are found in good agreement with same properties found in relevant literature. Values that describe the MSW characteristics agreed well with those of developing countries, i.e. food waste stream were found to be the largest stream composing more than 60% of the overall waste.

Plastic streams come second with more than 10%. Calorific values for food waste, plastics, paper and cardboard, textile and wood are found to be 16, 39, 17, 15, and 18 MJ/kg respectively. The heat content of a 100 kg of MSW contains 84.2 kg of Combustible MSW streams which is energy terms equals 2672 kWh (962 MJ). This is considered high energy potential. The research enabled identification of proximate properties including moisture content, volatile matter, ash content, and fixed carbon. These identified properties are prerequisite for any mathematical model that may be used in the future for further study energy generation options. On the basis of generated municipal solid waste and in particular combustible waste streams, waste-to-energy system may provide an opportunity for Palestinians to enhance the previous method to get the advantage of incineration. Moreover; it is recommended to conduct thorough technical and financial feasibilities on the best incineration system that suits Palestine.

الملخص

تحظى عملية تدوير المخلفات باهتمام كبير ومتزايد في دول العالم، وخاصة الدول المتقدمة، حيث أنها تعتبر من الصناعات المهمة ذات العائد الاقتصادي المجزي.

تعتبر المخلفات في فلسطين مشكلة كبيرة على البيئة والصحة، فنتيجة للظروف السياسية السائدة والحصار الاقتصادي، فإنه وفي كثير من الأحيان لا يتم جمع المخلفات والتخلص منها أو إعادة تدويرها بالشكل الصحيح، ونتيجة لذلك فإن هذه الممارسات تشكل خطراً على البيئة والصحة، وبالرغم من كل الظروف الصعبة بدأ العمل وبشكل حثيث على وضع خطط واستراتيجيات للتخلص من هذه الآفة، سواء أكان ذلك عن طريق إدارة وإعادة تدوير هذه المخلفات أو التخلص منها نهائياً.

هذا البحث يقوم على التركيز في تحديد كمية ونوعية النفايات الصلبة البلدية المتولدة وإمكانية تحويل النفايات إلى الطاقة من خلال قياس كمية وتركيب النفايات البلدية الصلبة المتولدة في المناطق السكنية الواقعة في مدينة الخليل، حيث تم جمع العينات المستخدمة وفق معايير الجمعية الأمريكية لتحديد الخصائص الحرارية وكذلك فحص محتوى الرطوبة، والمواد المتطايرة، ومحتوى الرماد والكربون والعلاقة بينهما وتم فحصها وإجراء التجارب عليها في مختبرات وحدة أبحاث الطاقة البديلة والبيئة في جامعة بوليتكنك فلسطين.

تمت الدراسات والتجارب على عينات ممثلة لتحديد الخصائص الحرارية والتحليل التقريبي والتي يتم تنفيذها لتحديد الخصائص الأخرى ذات العلاقة، وقد تم الحصول على الخصائص التي تم تحديدها بشكل تجريبي وهي متوافقة بشكل كبير جداً مع نفس الخصائص الموجودة في الكتب والدراسات ذات الصلة، اعتماداً على أساس حرق النفايات البلدية الصلبة القابلة للحرق، وهذه الخصائص متوافقة بشكل كبير مع الخصائص للنفايات الصلبة البلدية في الدول النامية. تبين أن فضلات الطعام تشكل ما نسبته أكثر من 60% من إجمالي مكونات النفايات البلدية، ويأتي في المرتبة الثانية البلاستيك حيث يشكل ما نسبته أكثر من 10%، كما تبين أن القيم الحرارية لفضلات الطعام 16 MJ/kg، البلاستيك 39 MJ/kg، والورق والكرتون 17 MJ/kg، النسيج 15 MJ/kg، الخشب 18 MJ/kg.

إن المحتوى الحراري لكل 100 kg من النفايات الصلبة البلدية تحتوي على 84.2 kg ممكن حرقها ويمكن الحصول على 2672 kwh أي ما يعادل 962MJ، حيث تعتبر هذه كمية كبيرة من الطاقة الكامنة.

من خلال هذا البحث تم تحديد الخصائص والتي تحوي: محتوى الرطوبة، المواد المتطايرة، الرماد، نسبة الكربون الثابتة، هذه الخصائص التي تم تحديدها هي شرط مسبق لأي نموذج رياضي يمكن استخدامه في المستقبل لدراسة المزيد من خيارات توليد الطاقة على أساس الكميات المتولدة من النفايات الصلبة البلدية وخصوصاً القابلة للاحتراق. إن نظام تحويل النفايات إلى طاقة يتيح فرصة كبيرة للفلسطينيين، بعد عمل دراسة جدوى اقتصادية وفنية بشكل دقيق، والذي يعتمد أساساً على تدفقات كمية النفايات الصلبة الناتجة ذات الطاقة الكامنة التي تم تحديدها بشكل تجريبي في إطار هذه الدراسة.

Table of contents

Dedication	i
Declaration	ii
Acknowledgments	iii
Abstract	iv
المخلص	v
Table of contents	vi
List of Tables	ix
List of Figures	x
Abbreviations	xii
1	
Chapter I	1
1.1 Introduction	1
1.2 Impacts of Solid Wastes on the Environment	3
1.3 Solid Waste Categories and main Constituencies	4
1.4 Municipal Solide Waste Management Options	6
1.5 Status of Solid Waste Management in Palestinian National Authority	8
1.6 Specific Problems associated with MSW Management in the PNA	10
1.7 The legal framework and legislation governing management of MSW in PNA	11
1.8 Management of MSW in the Hebron District and Hebron City	12
1.8.1 Geographical Background of the region	13
1.8.2 The Situation in Hebron City.....	14
1.9 A review of heat recovery option for the management of MSW.....	15
1.9.1 Advantages and Disadvantages of MSW Heat Recovery by Incineration	20
1.9.2 Potentials of the Incinerations	21
1.10 Statement of the Problem	22
1.11 Research Objectives.....	23
1.12 Hypothesis	23

2	Chapter II	24
2.1	Research Methodology.....	24
2.2	Identification of a municipality representative area for sampling.....	24
2.3	On-site sampling of MSW.....	26
2.4	Separation of Samples.....	28
2.5	Identification of constituents' properties.....	29
2.5.1	The density.....	29
2.6	Proximate Analysis.....	29
2.6.1	Moisture content.....	30
2.6.2	Volatile Matter.....	31
2.6.3	Ash Content.....	32
2.6.4	Fixed Carbon.....	33
2.7	Identification of thermal properties.....	33
2.8	Heat of combustion	34
2.9	Energy Content of MSW.....	43
2.10	Calculation Energy Equivalent (Standardizing the Calorimeter).....	43
2.11	Calculation of the Heat of Combustion	44
2.11.1	Gross Calorific Values.....	45
2.11.2	Calorific Values.....	46
3	Chapter III	47
3.1	Results and Discussions	47
3.2	Composition of MSW by weight	47
3.3	The MSW density	49
3.4	Proximate analysis	50
3.4.1	Moisture Content	50
3.4.2	Volatile Matter	53
3.4.3	Ash Content	54
3.4.4	Fixed Carbon	55
3.4.5	Proximate analysis	56
3.4.6	Calorific Values	56

3.5	Energy Content in MSW	59
3.5.1	Compound Samples	60
4	Chapter IV	61
4.1	Conclusion	61
4.2	Recommendation.....	62
5	References	63
6	Annex 1.....	71
7	Annex 2.....	76
8	Annex 3.....	80
9	Annex 4.....	81
10	Annex 5.....	84
11	Annex 6.....	97
12	Annex 7.....	100

List of Tables

No.	Table Name	Page
1.1	Comparison between developed and developing countries	4
1.2	Populations' projects for Hebron city, source	14
2.1	Dates all collecting samples	28
2.2	Average of energy equivalent factor, standard deviation	44
2.3	Values of energy equivalent factor experiments	44
3.1	Mean weight composition of MS in the study area	47
3.2	Average and range density of waste types	49
3.3	Moisture content values through June –November 2010	50
3.4	Values of MC, A, VM and FC for each waste streams	55
3.5	GCV, Stan. Dev., MC, NCV as received	58
3.6	Results use 100 kg of MSW streams	59
3.7	Calorific value of compound samples	60

List of Figures

No.	Figure Name	Page
1.1	Solid waste dumping sites in the West Bank	10
1.2	Hebron district	13
2.1	Flowchart illustrating experimental work performed	24
2.2	Study area in Hebron city	25
2.3	Random sample shoveled by the bulldozer bucket	26
2.4 a	Mechanism of coning and quartering method	27
2.4 b	Coning and quartering method	27
2.5	Separated samples	28
2.6	Measure the weight to check density	29
2.7	Drying samples in a special oven	30
2.8	Moisture content experiment	31
2.9	Ash content experiment	32
2.10	Bomb Calorimeter (1341 Parr)	34
2.11	Grinding machine	34
2.12	Solid samples (pellet)	35
2.13	Balance with sensitivity of 0.0001g	35
2.14	Putting the sample in the cup	36
2.15	Fuse wire Parr 45C10 nickel alloy	36
2.16	Closing Oxygen Bomb.	37

2.17	Oxygen cylinder with gauge pressure	37
2.18	Filling the calorimeter bucket with water	38
2.19	Attaching the lifting handle to the two holes in the side of cap.	38
2.29	An oxygen bomb calorimeter	39
2.21 a	Pre-fire equilibrium curve	40
2.21 b	Equilibrium curve	40
2.22	An example of (temperature, time) data plot	41
3.1	MSW distribution percent by weight- study area	48
3.2	Shows average moisture content of waste types	51
3.3	Average VM of waste types	53
3.4	Average ash content of waste types	54
3.5	Average fixed carbon of waste types	55
3.6	Average Gross Calorific Values for each waste streams	57

Abbreviations

A	Ash Content
ASTM	American Society for Testing and Materials
ARIJ	Applied Research Institute – Jerusalem
EQA	Environmental Quality Authority
Eq.	Equation
Fig.	Figure
FC	Fixed Carbon
GCV	Gross Calorific Value
HCV	High Calorific Value
HCSW	Health-Care or medical Solid Wastes
ISSWM	Integrated Sustainable Solid Waste Management
ISW	Industrial Solid Waste,
LCV	Low Calorific Value
MSW	Municipal Solid Waste.
MC	Moisture Content
NSSWM	National Strategy for Solid Waste Management
PNA	Palestine National Authority
PCBS	Palestinian Central Bureau of Statistics
SW	Solid Wastes
UNEP	United Nation Environment Programmed
VM	Volatile Matter

Chapter I

1.1 Introduction

Management of solid waste (SW) is considered a major challenge for the administrators, planners, engineers, and decision makers. Huge amount of daily generated SW needs collection, transportation, which is either disposed into proper landfills or sent for recycling or energy recovery. These successive procedures should be carried out effectively and feasibly in an appropriate time while mitigating any environmental or health impacts. It is unfortunate that in many developing and least developed countries, management of generated SW is not adequately performed resulting in several adverse problems for the local environment and the community.

With the steady population growth, notably, in the developing and least developed countries, growth in generated SW will be even more especially with the growth in urbanization. Therefore, the global dimension, management of SW is becoming a major challenge that faces sustainable development. Without the integrated approach in the management of SW, global problems such as climate change will terribly affect all internationally planned actions including the millennium development ones. An integrated management allows tackling the management of SW by integrating all management plans with national sustainable development strategies that preserve the environment and prohibit the dwindling of natural resources.

While most developed countries implement an integrated approach in dealing with the generated SW, other countries in particular developing and least developed ones are seen lagging behind. However, while SW is a national or local concern, it turned to be in the last decades a global concern as it could directly and indirectly affect the global environmental settings. To quantify the problem, it could be estimated based on a daily global-average per capita generated waste of 300 gram, when considering the current global population that exceeds six billion (PRB, 2010), means an average daily generated 2.0 billion-ton of overburden SW. This agrees well with the 1997 estimated situation of 0.49 billion-ton (Tong et al., 2001) and means an estimated doubling time for generated SW of 4-5 years, which means a serious problem that faces future generations and if considering the realistic population growth scenarios until 2030 and the expected associated expansion in

urbanizations, especially in several mega cities, e.g. in India, China and USA, (USCB, 2010), then the results would form huge sustainable development challenges in a short coming period of two decades.

The last three decades witnessed the development in urban areas over rural ones in a process called urbanization. Growth of urbanization is much more in developing countries than the developed countries to the extent that it became a trend that characterized several developed and even least developed countries. Growth in urbanization is coupled with the growth of population living in urban areas. In China, urbanization led to increase in urban population to about 35% percent of its total population with annual growth in urban population of about 4%. Similarly, it is anticipated that by 2025, Asian urban population will reach 50% of the total population and probably more. This expected increase will cause major shift in the distribution of the countries' populations and will lead to the expansion of urban boundaries (World Bank, 2004).

MSW is normally assumed to include all of the waste generated in a community, with the exception of waste generated by municipal services, treatment plants, and industrial and agricultural processes (Tchnobanoglous, G., 2002). In the urban context the term MSW has special importance since the term refers to all wastes collected and controlled by the municipality and comprises of most diverse categories of wastes. It comprises of wastes from several different sources such as, domestic wastes, commercial wastes, and institutional wastes and building materials wastes, essentially the same as waste normally generated by households and collected and disposed by normal MSW collection services. Such MSW is considered a problem that having impacts on the environment and the public health if not properly managed.

Comparing conditions related to MSW management in developed and developing countries brings indicators that quantify the problem. Considering the MSW generated in general, its main constituents are to some extent similar throughout the world, but the quantity generated, the density and the proportion of streams vary widely from country to country depend mainly on the level of income and lifestyle, culture and tradition, geographic location and dominant weather conditions. Low income countries with yearly per capita gross domestic product that does not exceed US\$ 5000 have the lowest MSW generation rates, which are in the range 0.3 – 0.9 kg/capita/day. The increase in per capita daily

generated waste is found linearly proportion to the per capita. In high income countries it reaches a range of 1.4 – 2.0 kg/capita/day (Khatib, I., 2011).

In urban areas of most developing and least developed countries generated MSW is at best collected and dumped in arbitrary dump sites that mostly lack the appropriate norms. Such disposal requires collecting, transport and dumping into the nearest open space area. In other countries MSW is dumped into water bodies and wetland and part of the waste is burned to reduce its volume. Such practices have their adverse environmental impacts ranging from polluting the natural resources and the ecology to the creation of health problems which might turn into long-term public health problems.

Studies that are conducted in the last decade in several developing countries showed those same old non-environmental practices are still used. Although lots of significant efforts have been done in the last few decades in many developing countries supported technically and financially by developed countries and international organizations, substantial reforms in the management of MSW are still not attained. This is due to the fact that frameworks recommended where mostly similar to that adopted in developed countries but without seriously addressing the socio-economic differences between the developed and developing countries.

1.2 Impacts of Solid Wastes on the Environment

Unless properly managed, SW has the potential of serious impacts on the environment. This can be summarized in the following:

- It can lead to surface and ground water contamination.
- It can lead to land pollution.
- It can lead to air quality deterioration.

Water infiltrating through the waste generates leachate, which can ultimately mix with the ground water. Dust and litter scattered by wind are responsible for deterioration of air quality in the vicinity of disposal sites. Decomposition of wastes releases noxious gasses posing high risk to human health.

1.3 Solid Waste Categories and main Constituencies

SW in general consists of the highly heterogeneous mass of discarded materials from the urban community, as well as the more homogeneous accumulation of agricultural, industrial, and mining wastes. The principal sources of SW are residences, commercial establishments and institutions, industrial and agricultural activities. Domestic, commercial, and light industrial wastes are together considered as urban wastes. The main constituents of urban SW are to some extent similar throughout the world, but the quantity generated, the density and the proportion of constituents vary widely from country to country, and from town to town within a country according to the level of lifestyle, geographic site, weather, and social conditions (Sufian, M. 2006). Per capita daily generated MSW is also a parameter that reflects the level of development and economical conditions. This is clearly reflected when distinguishing between a developed and developing countries in per capita generated waste in (Table 1.1).

Table 1.1: Comparison between developed and developing countries, (Source: Alavi Moghadam et al., 2009, Al-Salem, S., 2007, Municipality of Geater Amman, 2007, ARIJ, 2006. Alamgir, M. et al. 2005. METAP, 2004. Bennagen, Ma. et al 2002. Frenkel, M., 1993. Fobil, J, 2001. Gabbay, S, 2002. Alam, J. B. 2007. Khan, Iqbal, 2001. Kreith, F, 1994. Metin, E, 2003. NEERI, 1996)

SW indicator	Developed Countries	Developing Countries
(kg/cap/day)	0.88 – 2.09	0.31 - 1.4
Organic Stream, % weight	12.5 - 29	36 - 80.2
Recyclable % (Glass, Plastic, Metal)	20.2 - 27	8 - 18.7

Clearly, the table shows that developing countries produced less per capita SW as compared to figures from developed countries. The Major MSW stream is the organic waste, which is mainly the left-over food and waste, and it forms the main MSW stream in developing countries compared to the situation in developed ones. Even in developing countries economic situation, such as income is a major factor that affect the amount of generated MSW

MSW is a heterogeneous mixture of paper, cardboard, plastic, rubber, textile, metal, glass, food waste, etc. generated from households, commercial establishments, and markets. The proportion of different constituents of waste varies from season to season and place to place, depending on the lifestyle, food habits, standards of living, the extent of industrial and commercial activities in the area, etc (Katju, C., 2006).

All SW categories that include materials discarded for disposal by households, including single and multifamily residences, and wastes from canteens/restaurants and hotels and motels and from commercial and industrial entities essentially the same as waste normally generated by households and collected and disposed by normal MSW collection services are referred to as MSW. Industrial solid waste (ISW) is not similar to households' generated wastes. Also, health-care or medical solid wastes, and hazardous solid wastes that are generated by industrial processes or energy conversion process such as nuclear wastes are not considered MSW.

MSW category forms the major generated SW and may reach up to 50% of the total generated wastes by volume or even more (World Bank, 2004). The regular MSW streams diverse and usually consist of the following (Asian Institute of Technology, 1991):

1. Organic Matter: Waste from foodstuff such as food and vegetable refuse, fruit skin, stem of green, corncob, leaves, grass and manure.
2. Paper and Cardboard: Paper, paper bags, cardboard, corrugated board, box board, newsprint, magazines, tissue, office paper and mixed paper (all paper that does not fit into other category).
3. Plastic and Rubber: Any material and products made of plastics such as wrapping film, plastic bag, polythene, plastic bottle, plastic hose and plastic string. any material and products made of rubber such as ball, shoes, purse, rubber band and sponge.
4. Textile: Has its origin from yarn, wood and bamboo such as cotton, wool, nylon, cloth.
5. Wood: As desk, chair, bed board, toy and coconut shell.
6. Metal: Ferrous and non-ferrous metal such as tin can, wire, fence, knife, bottle cover, aluminum can and other aluminum, foil, ware and bi-metal.

7. Glass: Any material and products made of glass such as bottles, glassware, light bulb and ceramics.
8. Others: Yard waste, tires, batteries, large appliances, nappies/sanitary products, medical waste, miscellaneous.

The distribution of the diverse streams in a unified MSW size measuring unit depends mainly on the economical conditions and lifestyle (Sufian, M. 2006), per capita daily generated MSW is also a parameter that reflects the level of development and economical conditions.

The diverse quantities of streams are prerequisite information for solid waste management plans and scenario options. Management is strongly required to minimize any threat that MSW may impose on the environment and public health in addition to its effect on land-use and natural resources.

1.4 Municipal Solide Waste Management Options

Management of MSW refers to activities pertaining to the control, collection, transportation, processing, and disposal of MSW streams in accordance with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations. It includes all the procedures from the source and final disposal which should not have any harmful effect to the environment or least environmental effect that could be integrate by any physical or technical or social activities. This management also includes all attendant administrative, financial, legal, and engineering functions.

The objective of solid waste management is to reduce the quantity of SW disposed off on land by recovery of materials and energy from SW. This in turn results in lesser requirement of raw material and energy as inputs for technological processes.

The best management option entails the reduction and re-use of generated waste at source. However, such option is not feasible in a developing low income entity as it requires technological interventions that reduce the packaging of products in weight and size, and the production of disposals products that may be re-used at source. Other options are the reduction and reuse using recycling/composting techniques in addition to land filling.

Recycling techniques require considerable investment and dynamic market; however, composting of the biodegradable wastes certainly helps in reducing the size of the waste in addition to the benefits which offers in providing organic fertilizers for the agriculture sector. Incineration of waste is an option that requires considerable investment and human capacity in addition to tight regulations and technicality that ensure the safeguarded of the local environment and the public health.

It is therefore clear that solid waste management is an important environmental and economic priority in all countries. As the management of this sector is strongly dependent on all aspect of development, management should be tackled in an integral and sustainable approach. An integrated management of solid waste requires a comprehensive approach for each stage of solid wastes management, e.g. generation, collection, processing and final disposal to important components of integrated systems include the following:

- Wastes Minimization: Wastes should be ideally minimized at the source of its generation; reduction can be affected in many ways.
- Material Recovery and Recycling: MSW consist of various materials e.g. papers and cardboard, plastic, metals, glass, many of these components are recycling and reuse. The process involves separation and collection for reuse and remanufacture.
- Waste Transformation: It is the physical, chemical or biological convention of wastes for any beneficial purpose e.g. composting, incineration, and gasification.
- Volume Reduction: It is carried out before its final disposal. It includes size reduction through shredding, size separation through screening and volume reduction through compaction.
- Wastes Disposal: Wastes that can not be recycled or transformed need to be disposed off. Residues from various wastes transformation processes also need final disposal.
- Database Management: Available of precise and reliable data importance in the planning and design of any environmental system. (Khan, 2001).

There are many options in the management of solid waste in developing countries. In Egypt, an Arab-African country, 75% of waste is generated in urban areas. Experts expect that the total SW in 2025 will be more than 33 million tons for growth rate 3.2 according to

records 2001. The waste collection service covers less than 30% of urban and rural areas and the rest of deprived areas. (METAP, 2004).

1.5 Status of Solid Waste Management in Palestinian National Authority

Palestinian areas of the West Bank and Gaza strip are considered small and geographically divided. Under the current conditions, both areas are experiencing the control of the occupation force and hence are considered as the Palestinian National Authority (PNA). The territories in the West Bank are fragmented by the Israeli occupation and in Gaza strip the area itself is under the Israeli siege. The number of Palestinians live in the West Bank is 2.448 million whereas number of Palestinians in the Gaza strip is 1.486 millions (PCBS, 2009). In both areas of the PNA, development is so critical for many reasons of which are the limited lands and natural resources, in particular water. The pressure on land and natural resources decisively limit the option that planners have when addressing sustainable development. In such context, management of the generated MSW is one of the most severe challenges that Palestinians are facing as without a proper management that ensures mitigation of any possible adverse impact and the considerable reduction of the waste, the local environment and the public health will be under steady and continuous stress.

The Current situation that describe the total generated SW in 2009 shows that the amount of SW produced in the Palestinian Territories is estimated, according to the Palestinian Central Bureau of Statistics, at 78,644 tons per month, with organic waste constituting about 80% of that amount. The daily production rate of residential SW was estimated in 2009 at about 2,321 tons per day (1,710 in West Bank, 611 in Gaza Strip). The average daily residential SW production per dwelling is 3.5 kg/day (3.9 in West bank and 2.7 in Gaza Strip), at an average rate of 0.6 kg/capita/day (0.7 in West Bank, 0.4 in Gaza Strip). The quantity of SW produced varies according to the type of locality (city, village, refugee camp), and according to the type of prevailing economic activity and consumption patterns. Based on data available from the Palestinian Central Bureau of Statistics for 2009, the amounts of SW produced by healthcare centers were estimated at 1,202 ton per month (472 in West Bank, 730 in Gaza Strip). SW from the industrial establishments was estimated at 7,807 ton per month (6,308 ton in West Bank, 1,499 ton in Gaza Strip) (NSSWM, 2010).

References showed that the SW collection services in the West Bank and Gaza Strip cover almost 67% and 95% of the total population, respectively. In the West Bank, approximately 381,000 tons of MSW are collected and dumped every year in 189 open and uncontrolled dumping sites, whereas the remaining waste, approximately 214,000 tons are dumped and burned every year on roadsides and vacant lands. Open burning of collected SW is practiced in all the open dumping sites except Abu Dies site in the Jerusalem District and Nablus site in the Nablus District where the waste is land filled. (Isaac, J. et al., 2003).

In the Gaza Strip, approximately 300,000 – 350,000 tons of SW are generated every year. Around 247,000 tons are disposed of yearly in three sanitary landfills which are Gaza, Deir Al Balah and Rafah landfills. The remaining waste is dumped and burned in uncontrolled dumping sites and vacant lands near the Green Line. Approximately 61% of the total SW quantity dumped in the sanitary landfills is of organic origin. According to the Environmental Quality Authority (EQA), Gaza sanitary landfill has liner and leachate collection and treatment systems, whereas the two others do not as they are located on impermeable ground outside the recharge area of the coastal aquifer (Isaac, J. et al., 2003).

Moreover, Gaza sanitary landfill has a hazardous waste cell for disposal or storage of expired medicine and chemical laboratory waste. This cell has a life span of eight years and receives both untreated liquid and SW from all over the Gaza Strip. It is worth indicating that several pilot composting projects have been implemented in the Strip by non-governmental organizations.

Despite many hurdles, the PNA has scored some success in the last several years with the help of donating countries. In this respect, PNA has established regional sanitation landfills that serve different districts in the PNA, such as:

1. Zahrat Al-Funjan landfill in Jenin city.
2. Jericho landfill in Jericho city.
3. Deir-El-Balah in Gaza Strip.

In normal conditions, approximately 67 % of the West Bank population is serviced by a MSW collection system. Figure (1.1) shows SW dumping sites in the West Bank



Fig. 1.1: Solid waste dumping sites in the West Bank. (Source UNEP 2003)

1.6 Specific Problems associated with MSW Management in the PNA

Overall problems in solid waste management in the PNA can be summarized as:

1. Disruption of normal SW transportation routes due to a number of checkpoints being closed to Palestinian vehicles.
2. Lack of access to normal disposal sites for the same reason.
3. Lack of access to maintenance equipment and spare parts due to delays, transport difficulties caused by roadblocks, curfews and closures, and current import restrictions.
4. Dramatic increase in the waste generated from the destruction of buildings and infrastructure.

5. Introduction to open burning under the current situation.
6. Creation of emergency dumpsites within the urban areas, with the associated negative environmental and health impacts.
7. Increase in operational costs, adding to the financial burden on municipalities whose revenues have fallen sharply since September 2002 (UNEP, 2003).

1.7 The legal framework and legislation governing management of MSW in PNA

Before the establishment of the PNA in 1994, the administration of local services including SW under the Israeli Civil Administration since the Israel occupation of the West Bank and Gaza Strip in 1967 has been applied to health legislation of Jordan on west bank, based on the requirements of the Jordanian health, while in Gaza Strip has been applied the laws of the Egyptian Health (Hickman C., 2004).

The Palestinian legal framework provides the basis for broadly effective solid waste management on areas of the PNA, but its implementation needs to apply the laws and regulations are accurate and integrated and affected by the legal status of Palestine, now divided into three regions (A, B, C) depending on the degree of control by the PNA Only. Area A is under full Palestinian control; area B is under joint Israeli-Palestinian control and area C is under Israeli control, according to the Oslo Accords (Hickman C., 2004).

In addition to the amount of waste resulting from the large Israeli colonies located on Palestinian land inside the 1967 borders and that have been dropped at random and unorganized make the situation difficulty, Law No. 7 of 1999 entitled “Environmental Law” contains many provisions related to solid waste management.

Due to the challenges facing the SW sector in PNA and its major negative impacts on the water resources in particular, and on the environment in general, and the implication this has on the public health of the Palestinian citizen, in addition to the tremendous economical and social costs the Palestinian community bears, the Ministerial Cabinet took, on 2008, its decisions Formation of a committee to aiming at achieving the widest participation of partner national institutions as well as sponsor organizations. The PNA has convened a steering committee for the National Strategy for Solid Waste Management

(NSSWM) that is meant to be implemented over the period 2010-2014. NSSWM depends on the following policy principles (NSSWM, 2010):

- The principle of sustainable solid waste management, based on the optimal use of resources and environmental protection.
- Clarity of tasks and responsibilities and the separation between monitoring and organizational and executive duties.
- Easy availability of information and exchange functions transparently between all parties.
- Transparency of institutional, financial, monitoring, and administrative systems.
- The principle of partnership on the basis of clarity, confidence and integrity.
- Statement of the importance of all sectors of formal and informal.
- The importance of the role of community to participate in the management of MSW.
- Work on the basis of polluter pays and producer pays.

1.8 Management of MSW in the Hebron District and Hebron City

In Hebron district the MSW management services are usually the responsibility of the municipalities and village councils in urban and rural areas. In the refugee camps, the United Nations Relief and Works Agency for the Palestinian Refugees in the Near East (UNRWA) is the body responsible for providing solid waste management services. In addition to political conditions that significantly affect providing the services, the lack of proper funds and infrastructure are making solid waste management services as one of the most expensive services. Although municipalities and councils have assigned fees for the collection and transportation of wastes, few people were able to pay for the services and hence the revenue from the fees contributes to 70% of the money needed to run the services pay the remaining costs of municipal (UNEP, 2003, HJSC, 2010).

The Joint Services Council for the Hebron and Bethlehem districts, which is now responsible for the management of SW in the two provinces, will be establishing a sanitary landfill in Al-Minya region. It is anticipated that the landfill will be corresponding to international standards similar to the previously established "Zahrat Al-Finjan" landfill in

Jenin District. Further it is anticipated that the JSCHB will be closing Yatta dumpsite as soon as the new Al-Minya landfill is completed (HJSC, 2010).

1.8.1. Geographical Background of the region:

Hebron District is one of the districts in Palestine. According to 2010 Statistics Hebron has 86 localities populated by 600,364 inhabitants; Figure (1.2) shows Hebron district. Hebron city is located 30 Km south of Jerusalem. The climate in Hebron is temperate and means year-round temperature range between 15-16° ((an average of 7° in winter) and (21° in summer)). Annual precipitation average is around 502 mm. (HRC, 2010).

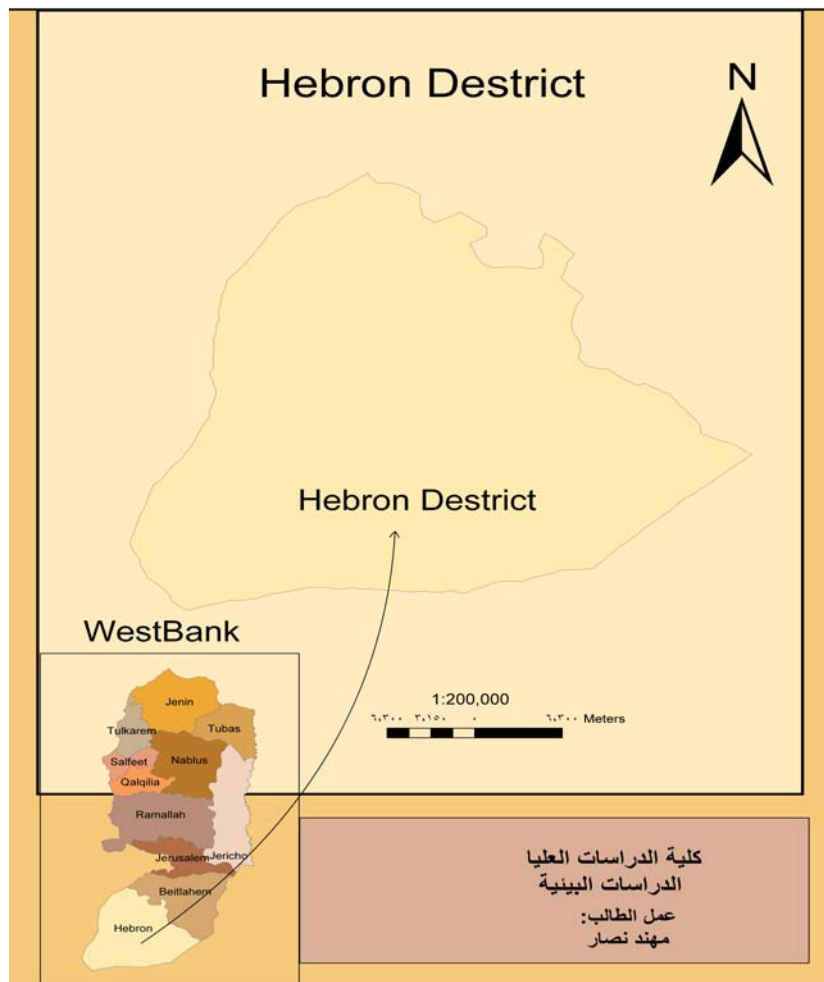


Fig. 1.2: Hebron district

1.8.2 The Situation in Hebron City

The amount of generated of MSW depending on the human activities domestic, commercial, industrial, agricultural and on Population size which is always a relevant factor in estimating majority of municipal services. The total generations of MSW are mainly depending on generation per capita; Table (1.2) shows summary of the populations' projects for Hebron city.

Table 1.2: Populations' projections for Hebron city, source (PCBS, 2010)

Pop./Year	2007	2008	2009	2010	2015	2020	2025
Hebron city	160,702	166,094	171,653	177,387	213,307	240,078	266,606

The fees for collecting, transporting and dumping of MSW is computed after calculating the running costs in each phase for the total tonnage collected monthly in Hebron (this includes workers, vehicles, fuel, maintenance, services and landfill). Hebron municipality charges usually 70% of the cost as fees paid by the beneficiaries and the rest 30% is subsidized by the municipality. A family may pay a fee of 22-28 Jordan dinners per annum for the services.

Hebron city is considered the largest in the West Bank and it hosts the largest industrial and commercial entities in addition to residential buildings (urban areas) expand over a large area. Hebron city generates some 180 tons of MSW which on the daily basis (Hebron Municipality, 2010). It is therefore; highly essential to reduce the generated waste effectively as if not managed properly, the environment and public health will be strongly impacted. Currently, there is a glass recycling industry in Hebron for touristic products, however, as glass usually constitute a small fraction of the overall MSW composition, other reduction options, including incineration and heat recovery, should be investigated. This does mean that other treatment options, including recycling, composting, and others, are not considered potentials. However, incineration as an option for a large city means considerable reduction of the waste, reduction of pressure on available lands and natural resources, and opportunity for generating energy for public use.

The research that is done in the framework of this thesis aims at quantifying the SW streams generated in the Hebron city and identifying each stream's characteristics and properties for incineration. The outcomes should give an assessment on the opportunities of utilizing heat recovery (waste-to-energy) in the Hebron city and could be generalized to other parts in the PNA areas. Before presenting the done, a review of the incineration as an option for MSW management is presented.

1.9 A review of heat recovery option for the management of MSW

Incinerator is usually an enclosed device using controlled flame combustion to thermally break down SW, including refuse-derived fuel, to an ash residue that contains little or no combustible materials.

Why it is useful for Palestine regarding the Incineration as a technique and its implications, and what background information can require?

- Properties of solid waste streams.
- Heat of combustion.
- Moisture content, etc.)

Incineration; which is also called waste-to-energy systems as it involves MSW heat recovery, is the combustion of waste in an excess of oxygen. Incineration is used throughout industry, particularly for medical waste and high-hazard material. Incineration and other thermal waste treatments can reduce the volume of MSW by 90% and its weight by 75% (European Parliament, 2000).

In several countries incineration accounts for more than 80-90% (Rand, T., et al. 2000) of the total generated MSW. It is believed that recent technology of incineration can generate more than 30 MW of electricity or desalinate more than 15 million cubic meters of saline water each year, by daily incinerating some 1000 tons of MSW.

There are several types of incineration technologies

1. Mass-burn Incineration.

Mass burn is combusting MSW without any pre-processing or separation. The resulting steam is employed for industrial uses or for generating electricity. Mass burn facilities are sized according to the daily amount of SW they expect to receive. Most mass burn plants can remove non-combustible steel and iron for recycling before combustion using magnetic separation processes. Other non-ferrous metals can be recovered from the leftover ash.

Mass burn combustion systems are designed to incinerate the MSW as collected without or with very little prior processing. The energy produced by mass burned combustion system depends upon the composition of MSW

2. Modular Incinerators.

Modular incinerators are small mass burn plants, with a capacity of 15 to 100 tons/day. The boilers for modular incinerators are built in a factory and shipped to the WTE site, rather than being built on the WTE site itself. The advantage of a modular WTE incinerator is flexibility. For example, if more capacity is needed, modular WTE units can be added. These facilities are used primarily by small communities and industrial sites. Costs limit the use of this technology because the return on investment in terms of energy produced over time is much lower than in mass burn plants.

Units designed for operation in the starved-air have historically been most common because of their ability to achieve sufficiently clean burning of the waste (i.e., relatively low particulate emission without the need for separate air pollution control equipment. This resulted in making the modular facility the least expensive facility to construct. New federal regulations however, have tightened particulate emissions limits, restricted acid gas emissions and subject the smaller capacity units to federal emissions regulations.

3. Fluidized-Bed Incinerators.

A fluidized bed type combustion system includes a steel vertical cylinder, lined inside with refractory bricks, and has a sand bed. Air nozzles called tuyeres are provided to inject air at high pressure. Solid fuel is injected into the cylinder. Auxiliary fuels such as natural gas or oils may be used initially to increase the temperature of the bed up to operational level 850 °C.

4. Refuse-Derived Fuel.

Refuse-derived fuel plants process of SW before it is burned. A typical plant will remove non-combustible items, such as glass, metals and other recyclable materials. The remaining solid waste is then shredded into smaller pieces for burning. It requires significantly more sorting and handling than mass burn, but can recover recyclables and remove potentially environmentally harmful materials prior to combustion. It can be burned in power boilers at factories or even at large housing complexes.

Sometimes refuse-derived fuel materials are "densified" (compacted at high pressure) to make fuel pellets. The "pellet fuel" may also include various sludge's, by-products of municipal or industrial sewage treatment plants. A major advantage of pellet fuel as an refuse-derived fuel is that it can be burned along with other kinds of fuel in existing power boilers. This means refuse-derived fuel pellet fuels can compete with traditional fuels, such as coal, on the open market.

The production of refuse derived fuels involves the mechanical processing of household waste using screens, shredders and separators to recover recyclable materials and to produce a combustible product. Systems involve the removal of inert and compostable materials followed by pulverisation to produce a feedstock which can be incinerated in power stations, pyrolysis and gasification systems

The first attempts to dispose of urban refuse through combustion in a furnace are reported to have taken place in the north of England in the 1870s (Goodrich, W. 1901). By the turn of the century, emphasis was placed on the development of furnaces capable of burning SW. During this time, a number of communities found incineration to be a satisfactory and sanitary method of waste disposal. The reason for the satisfaction lay in the fact that the main objective was to achieve maximum volume or weight reduction. Little or no concern was had for energy recovery or for control of air pollution from incinerators. The situation changed completely in the 1960s in that the majority of incinerators in the United States were closed down, primarily because of excessive particulate emissions. However, the popularity of incineration continued undiminished in Western Europe and often was made to include energy recovery.

One of the most effective means of dealing with many wastes, which reduces their harmful potential, and often to convert them to energy form (Tchobanoglous, G. 2002). Incineration is the controlled burning of waste in a purpose built facility. It involves the process of direct burning of wastes in the presence of excess air at the temperatures of about 800°C and above (The Expert Committee, 2002). The process sterilizes and utilizes the waste. For most wastes, it will reduce its volume to less than a quarter of the original. Most of the combustible material is converted into ash and carbon dioxide (Sathishkumar, R. et al 2000). In practice, about 65-80 % of the energy content of the organic matter can be recovered as heat energy, which can be utilized either for direct thermal applications, or for producing power.

MSW incineration, known as waste-to-energy incineration, is the combustion of waste at high temperatures. It can generate energy while reducing the amount of waste by up to 90% in volume and 75% in weight.

There are several types of incineration technologies including mass-burn incineration, modular incineration, fluidized-bed incineration and refuse-derived fuel production and incineration. The two are widely used and technically proven as incineration technologies are mass-burn incineration, and modular incineration (UNEP, 1996).

Depending on the national settings, priorities and capacity an ISSWM takes into account the best practices in the management processes. In most developed countries; incineration (waste-to-energy) is proven to be the best opportunity that allows reducing waste considerably.

Incineration has been used widely in Europe and Japan without any adverse health impacts. Switzerland, a country with high environmental standards, incinerates about 75 percent and Japan more than 50 percent of their SW, according to a survey by the Integrated Waste Services Association in the spring of 1993. Sweden incinerates 60 percent and composts up to 25 percent. But waste-to-energy combustion is only slowly gaining public acceptance in the United States. But as more information on this technology becomes available, political support for setting new facilities is likely to increase and pave the way for full integration of combustion in waste management schemes. (Tchobanoglous, G. 2002).

Another option for waste reduction and disposal is incineration. Incineration should not be considered a 'disposal' option, since following incineration there is still some quantity of ash to be disposed of (probably in a landfill), as well as the dispersal of some ash and constituent chemicals into the atmosphere. It should instead be considered more in terms of its waste-reduction potential, which can be 80-95% in terms of waste volume (Rand, et al 2000). This appears to be an extremely attractive option, however, with occasional exceptions, incineration is an inappropriate technology for most low-income countries. Above all, the high financial start-up and operational capital required to implement incineration facilities is a major barrier to successful adoption in developing countries (Rand et al 2000, UNEP 1996).

MSW issues represent major problems to the governments of developing nations. As poorer nations grow and develop, improvements in infrastructure and technology should help to overcome barriers to the safe disposal of urban waste. Environmental regulations, intelligently designed to protect the health and integrity of ecosystems and human populations, should be created and enforced now in order to prevent the need for costly remediation measures in the future.

The use of potential utilization sites for land filling MSW, as it is practiced in Santiago for cost reasons, represents a non-sustainable use of land because little can be done with this land after the landfill is closed. In consequence, accumulation of such a large volume of waste for long time is dangerous for the environment. Hence, one possible way to solve these problems with landfills is to reduce waste volume by burning through Waste to Energy technology.

Waste-to-energy has been recognized by the U.S., EPA as a clean, reliable, renewable source of energy. Worldwide, large amounts of MSW are combusted annually in facilities that produce electricity and steam for district heating and recovered metals for recycling (Smith, A. et al., 2001).

A station that provides KWh/ton of MSW of net electricity output to utilities is equivalent to a saving of fuel. In addition, a sophisticated air pollution control system is used to remove particulate and gaseous pollutants before the processes' gas is released into the

atmosphere, The combined bottom and fly ashes amount to 10 to 20% of the original MSW (Indaver, I. 2005) then can be collected using special filters and then buried in landfills.

1.9.1. Advantages and Disadvantages of MSW Heat Recovery by Incineration:

One of the most effective means of dealing with many wastes is to reduce their harmful potential and often to convert them to an energy form is incineration. In comparing incineration (the destruction of a waste material by the application of heat) to other disposal options such as land burial, the advantages of incineration are:-

1. The volume and weight of the waste are reduced to a fraction of their original size.
2. Waste reduction is immediate; it does not require long-term residence in a landfill or holding pond.
3. Waste can be incinerated on-site, without having to be carted to a distant area.
4. Air discharges can be effectively controlled for minimal impact on the atmospheric environment.
5. The ash residue is usually nonputrescible, or sterile.
6. Technology exists to completely destroy even the most hazardous of materials in a complete and effective manner.
7. Incineration requires a relatively small disposal area, compared to the land area required for conventional landfill disposal.
8. By using heat-recovery techniques, the cost of operation can often be reduced or offset through the use or sale of energy (Tchnobanoglous, G. 2002).

Incineration will not solve all waste problems. Some disadvantages include:

1. The capital cost is high.
2. Skilled operators are required.
3. Not all materials are incinerable (e.g., construction and demolition wastes).
4. Supplemental fuel is required to initiate and at times to maintain the incineration process.

As indicated previously, it is essential to consider the opinions of local citizens during the evaluation of the alternative options for SW processing management.

Concerning the SW processing methods, the most favorable option based on the perceptions of the interviewees in the West Bank is Land filling, followed by recycling, composting and incineration.

This is the a unique research type in Palestine Authority, it measures the properties of MSW such as calorific value, moisture content, volatile matter, ash content, fixed carbon, Therefore, there are no local studies of the comparison process.

1.9.2. Potentials of the Incinerations

There are many studies and success stories and experiences in the use of incineration for the production of energy in addition to the advantages mentioned earlier, And among them some research and studies as follow.

Evaluation of MSW for utilization in energy production in developing countries show that Calorific content of MSW from urban waste zones in Accra, Ghana are food waste 16.28-17.5 MJ/kg, paper and cardboard 16.82 – 19.23 MJ/kg, textile 16.11 – 16.97 MJ/kg. Moisture content 39.8 – 62.2 % (Fobil, J. 2002). These are proper values for incineration. In other European countries, e.g. Ireland, heat content of their MSW streams are estimated at 3.98 MJ/kg, 13.3 MJ/kg, 33.3 MJ/kg, 16.11MJ/kg, food waste, paper, Plastic and Textile respectively (Smith, 2001).

For assessing properly the incineration potential, the World Bank technical guidance report for MSW Incineration issued in 1999 suggested that the calorific values, moisture content and ash of MSW combustible streams are as follows: food waste 17 MJ/kg, 66%, plastics 33 MJ/kg, 7.8%, textile 20 MJ/kg, 7.8%, paper and cardboard 16 MJ/kg, 5.6%, and wood 17 MJ/kg, 5.2% (World Bank, 1999).

In Asian countries are nearly similar. In Malaysia, identified heating values and moisture contents of combustible MSW streams are as follows: food waste 15.85 MJ/kg, 75%, plastics 31 MJ/kg, 20%, paper 16 MJ/kg, 28% (EPA, 1995. Rotter, S. 2003) and in

Santiago energy content in food wastes 5.35 MJ/Kg, plastic 32 MJ/Kg, paper 16 MJ/Kg, and in textile 17.44 MJ/Kg (O'Leary, P. 1987).

Other available studies done on MSW for the city of Kuala Lumpur showed that heat of combustion for MSW streams and their ash content, moisture content are as follow: food waste 4-6.3 MJ/kg, 15-30%, 60-70 %, paper and cardboard 11- 17 MJ/kg, 8-9 %, 6-15 %, Textile 13-16 MJ/kg, 2-5%, 22.5 %, and for plastics 33-39 MJ/kg, 2-4.3 %, 10 % (Mark, F.E., 1994). In addition, some studies show that the range of calorific values and moisture content for the food waste 3.5-7 MJ/kg, 50-80 %, paper and cardboard 11.6 – 18.6 MJ/kg, 4-6 %, plastics 27.9-37.2 MJ/kg, 1-4 %, textile 15.1- 18.6 MJ/kg, 6-15 %, wood 17.4 -19.7 MJ/kg, 15-40% (Tchobanoglous, G. 2002).

1.10 Statement of the Problem

Improper management of solid waste may risk the environment and the public health. Environmental risks are those associated with the adverse impacts on water resources, land use, ecological settings, and air quality, whereas impacts on public health are those indirectly arose from the affected local environment. The world became aware of the necessity for reducing and/or treating of generated solid waste streams to insure sustainable development.

In Palestinian areas in general and Hebron city in particular, MSW management constitutes a major challenge for sustainable development as it is very much adversely influenced by the turbulent economical situation and the availability of proper lands. The problem is intensified because of the Israeli occupation measures which prohibit accessibility. Such problem necessitates finding answers to the following questions;

1. How could generated MSW be effectively reduced and treated in such persistent conditions?
2. What background information and data are required in order to assess effective reduction and treatment option?

1.11 Research Objectives

For the sake of assessing the potential of waste-to-energy option for Palestine, it is highly essential to study the properties and characteristics of the generated MSW.

In the following chapters, the status of MSW management in Palestinian territories will be elaborated based on the available literatures and communication with the relevant governing and service providing bodies. An area for the study is identified which contains urban extension only. This area in Hebron city, which is very identical to other Palestinian cities located in the West Bank. For the study area characteristics of the generated MSW is investigated experimentally and in situ. Based on the collected representative samples, experimental work is conducted to identify relevant properties for assessing the incineration option. The methodologies adopted are those identified by the ASTM standards and used in laboratories worldwide.

1. To determine the thermal properties of the generated MSW.
2. To assess the heat of content in the combustible MSW streams.
3. To assess the possibility of waste-to-energy in Hebron City.
4. To proper means for energy conversion.
5. Approximate analysis.

1.12 Hypothesis

The present study has the following hypothesis:

1. The final analysis of the current generated MSW correspond to situation in similar developing countries, in particular the MSW characteristics and properties.
2. The thermal properties of the combustible MSW streams are highly potential for heat recovery.
3. The proximate analysis properties of the combustible MSW streams are similar to those international values.

Chapter II

2.1 Research Methodology

The research carried out entails considerable experimental work that is performed on the field and in the laboratories using validated ASTM series. The substance is the MSW collected, sampled, processed, and tested in successive procedures each with its controlled environment and settings.

Figure (2.1) is an illustration of the processes implemented in realization of the research. The description of each flow chart item will be elaborated in this chapter. However, prior to conducting the research, the area of research study for sampling was identified.

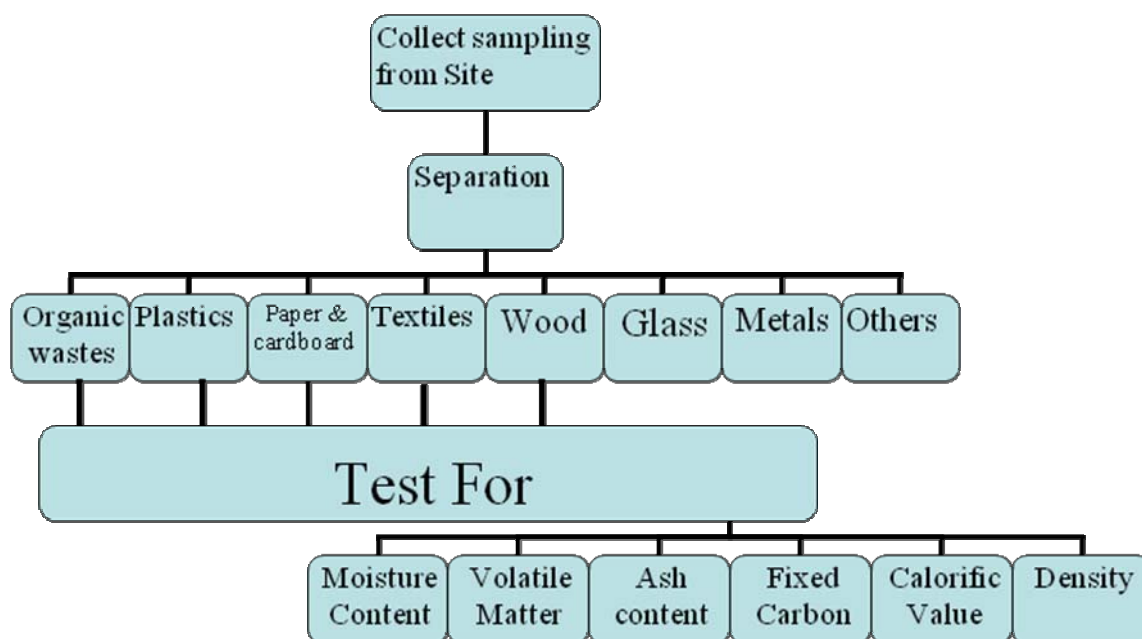


Fig.2.1: Flowchart illustrating experimental work performed

2.2 Identification of a municipality representative area for sampling

A representative area for sampling MSW was identified in Hebron city. The identification of the area is based on the conditions that such area does not have any industrial activities taking place in it and also it has no large commercial entities. This ensures to some extent

that MSW reflect typical residential wastes. Same residential area is located southwest of Hebron city as shown in (Figure 2.2). It has an average population of 12000 inhabitants. Hebron municipality provides waste collection services on daily bases, where an average of 10000 kg/day is usually collected and transported to the nearby dumpsite in Yatta, a town located 17 km away from the identified area.

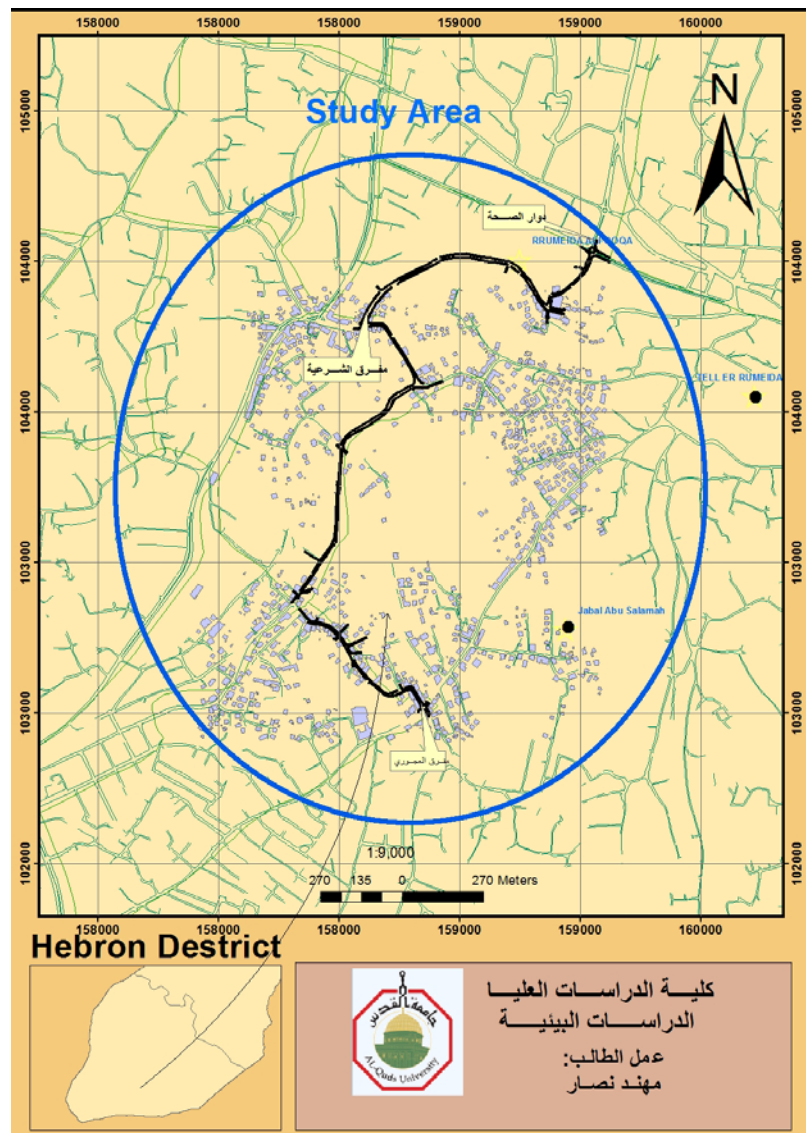


Fig. 2.2: Study area in Hebron city

2.3 On-site sampling of MSW

The total 10 tones of MSW collected and transported to Yatta dumpsite are used for sampling. This is done with the help of the workers at dumpsite. There, a bulldozer shovels the dumped wastes several times to ensure mixing of waste constituencies. Then a random sample is shoveled by the bulldozer bucket as seen in Figure 2.3. The weight of the sample shoveled is determined by weighing the bulldozer unloaded and then loaded. The shoveled sample separated from the total collected waste is then dumped in an open area. The sample weighing around 250 kg is divided into four blocks of wastes' piles use "Cone, and quarter method" as seen in (Figure 2.4a, and 2.4b). Two of the waste piles are mixed again in a one pile of around 125 kg. Then the piles are divided again into four smaller piles and again of them two small piles are then mixed in one single pile. The process is repeated until have a representative sample weighing 20-30 kg (ASTM D 5231- 2008).



Fig. 2.3: Random sample shoveled by the bulldozer bucket

To identify the constituencies forming the representative MSW sample, each constituent is segregated and arranged in piles that are weighted separately and used to identify the weight composition of MSW in weight. It is worth mentioning that sampling commenced over the period June – November 2010, taking into account the seasonal variation from summer to autumn and the fact that summer season is traditionally the season of social activities, e.g. marriage.

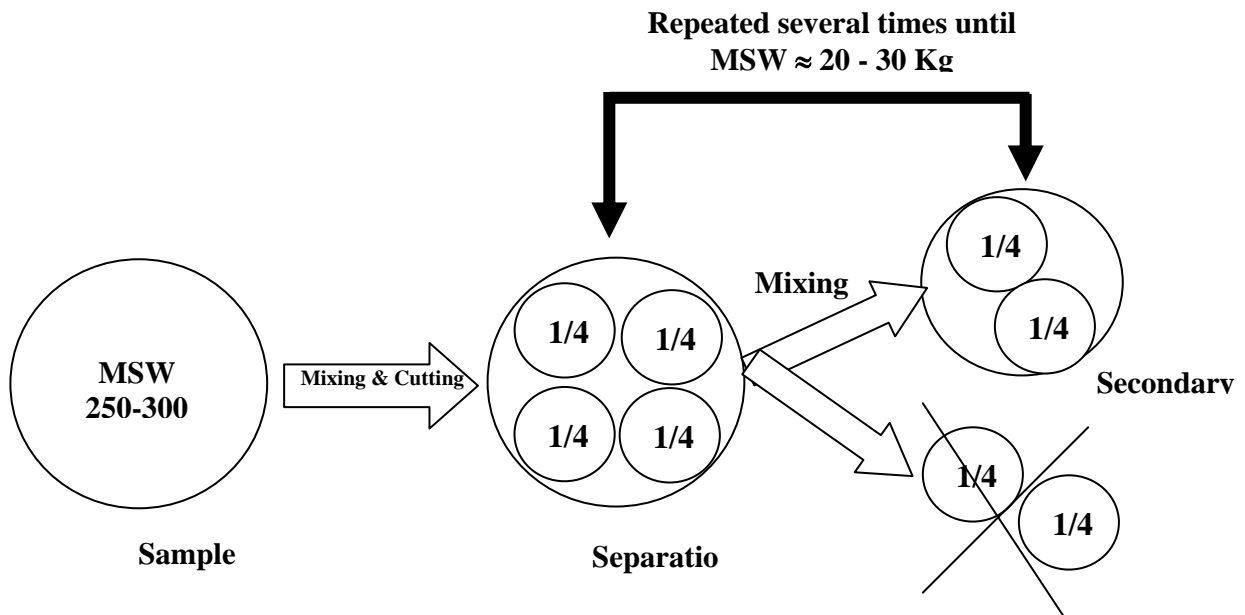


Fig. 2.4 a: Mechanism of coning and quartering method



Fig. 2.4 b: Coning and quartering method

Samples were collected from the landfill in the Yatta region according to (ASTM D 5231-2008) which covers the period between June – November 2010, taking into account the seasonal variation from Summer to Autumn and the fact that's Summer season is traditionally the season of social activities as it is shown in the table (2.1).

Table 2.1: Dates all collecting samples

Day	June 2010		July 2010				Sep.	October 2010				November		
Sun	20	26			18	25	25	3	10		31		7	
Mon	21	28		5			26							29
Tue.					13		27	5	12	26		2	23	
Wed	9			7		28			13			3		
Thu	24			8	15	22	29	30	7	14	28		25	
Fri														
Sat	19		3	10	17	24				23			27	

2.4 Separation of Samples

Figure (2.5) shows shoveled sample that is separated into to eight representative sample-piles each representing a MSW constituent, i.e.:

1. Organic and food overburden,
2. Plastic,
3. Paper and cardboard,
4. Glass,
5. Metals,
6. Textiles,
7. Wood, and
8. Others, which are those not characterizing MSW such as stones, diapers, tissues, etc.



Fig. 2.5: Separated samples

2.5. Identification of constituents' properties

Properties required to be identified are those needed to quantify the MSW streams physically and thermally, which include:

2.5.1. The density:

This is done for each sample stream by weighing the sample as in figure (2.6), in its loose form; i.e. not compacted, in a unified volume. The unified volume is a circular container of 400 mm diameter and a 500 mm height. To calculate the specific volume for each sample the equation 2.1 is used:

$$\text{Density} = (W_{WC} - W_C) / V_C \dots \dots \dots (\text{kg} / \text{m}^3) \dots \dots \dots (2.1)$$

Where;

W_{WC} weight of container filled with the wastes (in kg),

W_C weight of empty container (in kg), and

V_C volume of container (in m^3).



Fig. 2.6: Measure the weight to check density

2.6 Proximate Analysis

This analysis entails the identification of several important properties such as; moisture content, ash content, fixed carbon content and volatile matter. In the following, identification of each property and the test involved is going to be elaborated.

2.6.1. Moisture content:

The moisture content is a measure of the wet ability of the MSW. It is identified experimentally according to ASTM - D4843 (2009). It is necessary to measure moisture content for each sample in-situ on the same day when sampling MSW constituents are identified. This is done by weighing the different samples separately right before drying them in a special oven. Samples for measuring the moisture content are first weighted to 100-500 grams and then filled in specific cylindrical containers. The samples are then left in a special oven over 24 hours (Figure 2.7). During drying the samples, the oven temperature should be maintained at $60 \pm 2^\circ \text{C}$. After drying the samples over 24 hours, samples are then taken out of the oven and left to cool over another 24 hours in room temperature. The oven used for drying the samples is equipped with an internal fan and vented to external air to minimize odor nuisance. The measure moisture content is calculated using the formula 2.2:

$$\text{MoisterContent} = [(W_w - D_w) / W_w] \times 100 \% \dots\dots\dots (2.2)$$

Where:

W_w : Wet Weight

D_w : Dry Weight



Fig. 2.7: Drying samples in a special oven

2.6.2. Volatile Matter:

This is the product, exclusive of moisture content, given off by a material as gas or vapor. It is determined by using oven that can be set at a temperature of 1000C°. A sample of 1 g is then placed into a weighed crucible as seen in (Figure 2.8) and the crucible is sealed with its cover and placed into the oven chamber, with temperature maintained at 950 ± 20 C°. After 7 minutes, the crucible is removed from the oven, and left to cool at room temperature. The crucible weight is then recorded without disturbing the cover. (ASTM E 897-88- 2004). Volatile matter could be calculated by using equation 2.3.

$$V = \left[\frac{A - B}{A} \times 100 \right] - M \dots\dots\dots (2.3)$$

Where;

V: volatile matter, %

A: weight of sampled used, gr.

B: weight of sample after heating, gr.

M: moisture content.



Fig. 2.8: Moisture content experiment

2.6.3. Ash Content:

Ash is the non-combustible, solid by-product of incineration or other combustion process.

Its two types are:-

- Bottom ash: a toxic residue of incineration that accumulates on the grate of the furnace and is relatively coarse and non-combustible.
- Fly ash: a highly toxic particulate matter captured from the flue gas of an incinerator by the air pollution control system.

In order to identify ash content, a sample of 1 g weight is placed into a weighed uncovered crucible. The uncovered container with sample in it is then placed into the oven at low temperature and gradually heated to $725 \pm 25^\circ$ (Figure 2.9). Temperature of oven is kept constant for 1 hour. Weight is recorded after the crucible was cooled to room temperature (ASTM E 830-87- 2004) then ash content is determined using equation 2.4.

$$A_s = \frac{A - B}{C} \times 100 \dots\dots\dots(2.4)$$

Where;

As: ash content, %

A: weight of container and ash residue, gr.

B: weight of empty container.

C: weight of sample used, gr. (including residual moisture)



Fig. 2.9: Ash content experiment

2.6.4 Fixed Carbon

Fixed carbon content depends on identified properties and can be calculated using equation 2.5 as below (ASTM D 5681-98 a - 2008).

$$F_c = 100 - (M + V + A) \dots \dots \dots (2.5)$$

Where;

F_c: fixed carbon, %

M: total moisture, %

V: volatile matter, %

A: ash content, %

2.7 Identification of thermal properties

These properties are used to measure thermal performance of the MSW. Some of the thermal properties need measurements and others are derived properties. The thermal properties include:

- **Gross calorific value:** The heat produced by combustion of a unit quantity of solid fuel, at constant volume, in an oxygen bomb calorimeter under specified conditions so that all the water in the products remains in liquid form. (ASTM E 711-87 - 2004)
- **Net calorific value:** The heat produced by combustion of a unit quantity of solid fuel at a constant pressure of one atmosphere, under the assumption that all water in the products remains in the form of vapor. It has a net value than that calculated from gross calorific value.

Measuring the gross calorific values (heat of combustion) is done using a constant volume oxygen bomb calorimeter (Parr 1341) calibrated by a benzoic acid solid fuel, steps of calibration in annex 1. The bomb calorimeter burns the fuel sample and transfers the heat into a known mass of water. From the weight of the fuel sample and temperature rise of the water, the calorific value can be calculated. The calorific value obtained in a bomb calorimeter test represents the gross heat of combustion per unit mass of fuel sample. This

is the heat produced when the sample is burned, plus the heat given up when the newly formed water vapor condenses and cools to the temperature of the bomb. Figure (2.10) shows the bomb calorimeter assembled for use.



Fig.2.10: Bomb Calorimeter (1341 Parr)

In order to use the bomb calorimeter, samples should be first prepared in accordance to Parr Calorimeter manufacturing manual and guidelines. This is done as follows:

2.8 Heat of combustion.

1. A chosen MSW stream dried sample is collected, then using a grinding machine grinds to finest homogenized particles (powder shape) of 100-200 g see (fig.2.11).



Figure 2.11: Grinding machine

2. To form a solid sample (pellet), a portion of the grinded substance is taken and in pellet die of a pellet press as shown in (fig.2.12).



Figure 2.12: Solid samples (pellet)

The Parr pellet press should first be clean and dry and the amount of sample needed to form a pellet should first be weighted. Solid pellet sample may be produced from different MSW streams formed together similar to their composition of the generated MSW. Pellet weight should be measured using a balance with sensitivity of 0.0001g as in (fig.2.13).



Figure 2.13: Balance with sensitivity of 0.0001g

3. Weighing the sample (type of which needs to test its caloric value) on a balance having a sensitivity of 0.0001g. They have to ensure that the weight of sample doesn't exceed 0.7 g. Compressed with Parr pellet press (the weight of solid sample and benzoic acid pellet does not exceed 1.1 g), then put the sample in the cup as shown in (Figure 2.14) (ASTM E 711-87 – 2004).



Fig. 2.14: Putting the sample in the cup

4. Use fastens a 10 cm length of fuse wire between the two electrodes; Parr 45C10 nickel alloy wire is used for most tests as shown in the (fig.2.15) (Atkins, P. et al., 2002).



Fig.2.15: Fuse wire Parr 45C10 nickel alloy

5. Figure (2.16) shows Closing the Oxygen Bomb, Care must be taken not to disturb the sample when moving the bomb head from the support stand to the bomb cylinder.



Fig.2.16: Closing Oxygen Bomb.

6. Press the fitting on the end of the oxygen hose into the inlet valve socket and turn the union nut finger tight. Close the valve on the filling connection; Open the filling connection control valve slowly and watch the gage as shown in figure (2.17) the bomb pressure rises to (30 atmospheres); then close the control valve.



Fig.2.17: Oxygen cylinder with gauge pressure

7. Fill the calorimeter bucket, by first taring the dry bucket on a solution or trip balance; then add 2000 (+/- 0.5) g of water whose temperature has been adjusted to 19-21°C as (Fig.2.18). Note the exact mass of the water.



Fig. 2.18: Filling the calorimeter bucket with water

8. Set the bucket in the calorimeter; then attach the lifting handle to the two holes in the side of the screw cap and lower the bomb into the water with its feet spanning the circular boss in the bottom of the bucket then push the two ignition lead wires into the terminal sockets on the bomb head using a tweezer as in Fig.2.19.



Fig.2.19: Attaching the lifting handle to the two holes in the side of cap

9. Set the cover on the jacket with the thermometer facing toward the front. Turn the stirrer by hand to be sure that it runs freely; then slip the drive belt onto the pulleys and start the motor as in Fig.2.20.

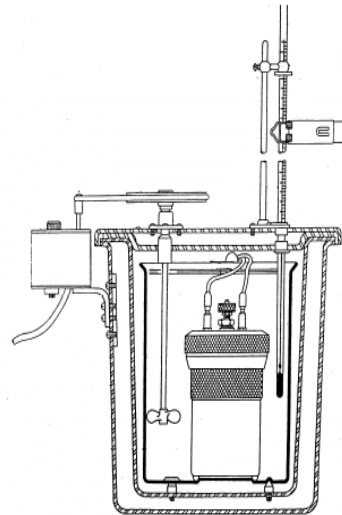


Figure 2.20: An oxygen bomb calorimeter.

10. Let the stirrer run for at least 5 minutes to reach equilibrium before starting a measured run.
11. The scanning of the temperature data is pre-set at every 15 seconds interval through 3 min. At the starting of the 10th minute, stand back from the calorimeter and fire the bomb when prompted by pressing the ignition button and holding until the indicator light goes out. Normally, the light will glow for only about half a second, but release the button within 5 seconds regardless of the light.
12. The bucket temperature will start to rise within 15-20 seconds after firing. This rise will be rapid during the first three minutes; then it will become slower as the temperature approaches a stable maximum as illustrated in the typical temperature rise curve shown in (Fig.2.21 a, b).
13. They have to measure the time required to reach 60 percent of the total rise by estimating the temperature at the 60% point and noting the time from the plot.

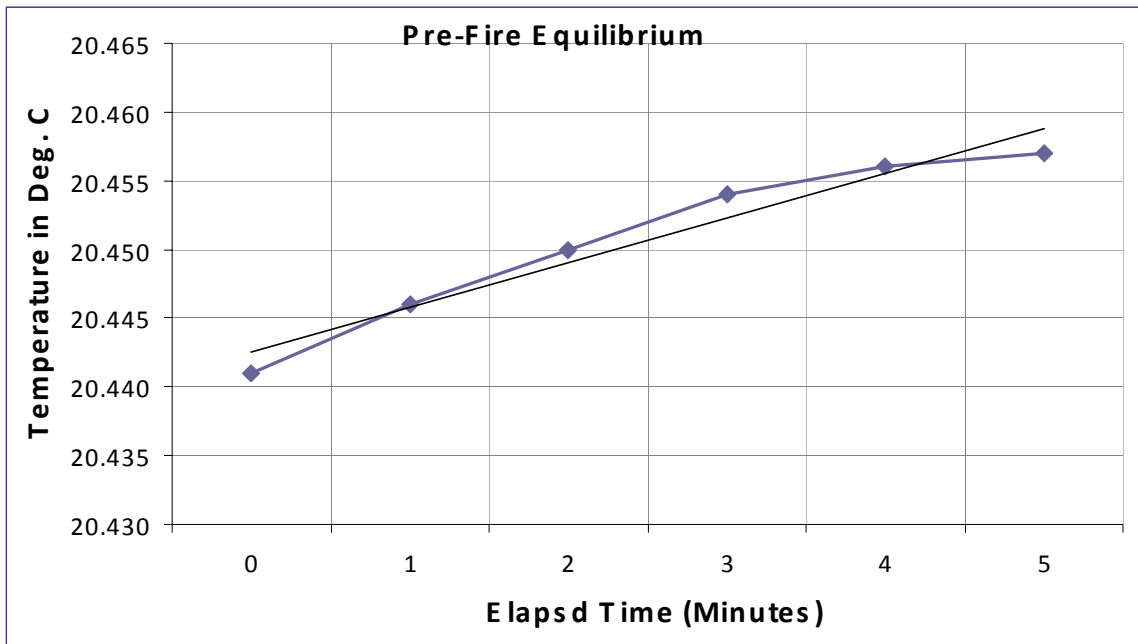


Fig.2.21 a: Pre-fire equilibrium curve

14. Usually the temperature will reach a maximum; then drop very slowly. But this is not always true since a low starting temperature may result in a slow continuous rise without reaching a maximum. As stated above, the difference between successive readings must be noted and the readings continued until the rate of the temperature change becomes constant over a period of 5 minutes.

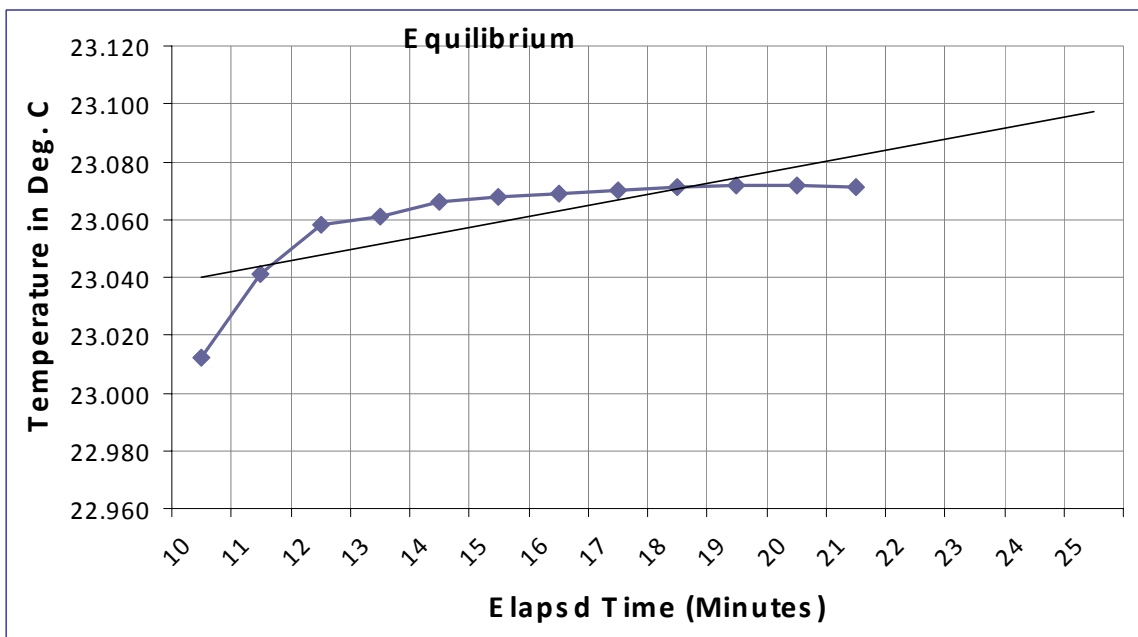


Fig.2.21 b: Equilibrium curve

In order to identify thermal property of SW constituent, each constituent sample is combusted in an oxygen bomb calorimeter in constant volume. The temperature-time relationship which is drawn during carrying out the experiment indicates the temperature needed to raise the water in the bomb a 1 C° which is used for each sample to identify the heat content of each sample based on the calorimetric value of the bomb calorimeter, all figures illustrate in annex 2. Figure (2.22) shows the temperature-time plot for each experiment and. Points of the graph denoted by 'a', 'b', 'c', 'i' and, 'f' reflect experiment status. Point 'a' denotes the time of firing of the bomb, 'b' the position where the temperature reaches 60 % of the total change, and 'c' the time of maximum temperature (i.e., end of the reaction). Points 'i' and 'f' denote the initial and final points of measurement, respectively. The accuracy for reading the points should be to nearest 0.1 min. A simple approach for obtaining the temperature rise would consist of subtracting the initial and final temperatures (e.g. $\Delta T = T_c - T_a$). However, if the temperature is not stable in the initial ($i < t < a$) and final ($f > t > c$) periods, baseline correction must be applied. If the baseline is assumed to be linear, the rates of change can be obtained by using a difference approximation:

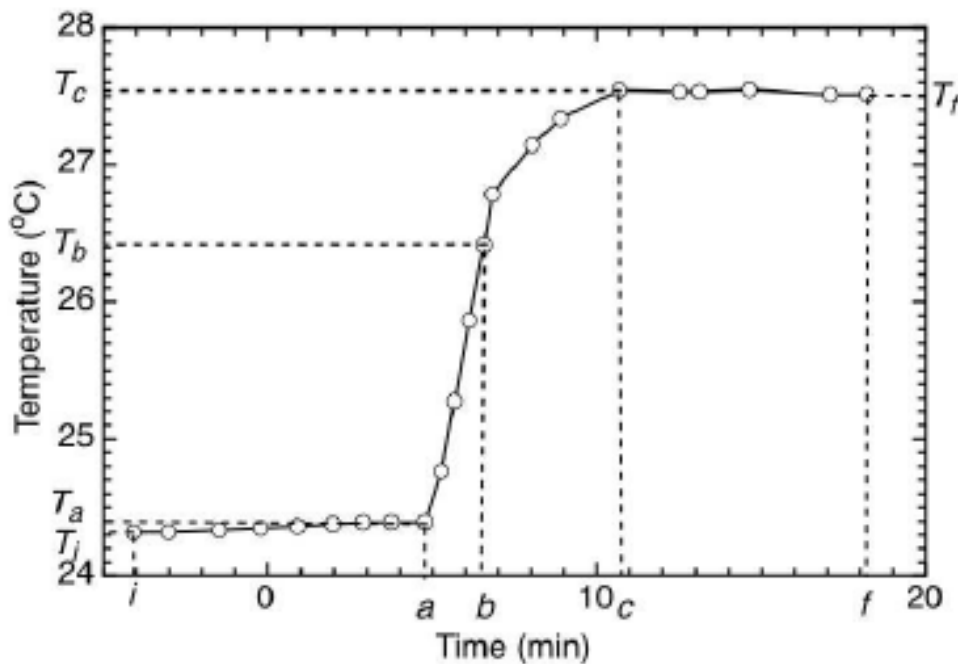


Fig.2.22: An example of (temperature, time) data plot showing the positions for reading T_i , T_a , T_b , T_c , and T_f .source (manual of bomb calorimeter)

The baseline is evaluated for a both initial and final temperatures about point b. ΔT is determined using equation 2.6.

$$\Delta T = (T_c - r_2(c - b)) - (T_a - r_1(b - a)) = T_c - T_a - r_1(a - b) - r_2(c - b) \dots \dots \dots (2.6)$$

Where:

a: Time of firing

b: Time (to nearest 0.1 min.) when the temperature reaches 60 percent of the total rise

c: Time at beginning of period (after the temperature rise) in which the rate of temperature change has become constant

Ta : Temperature at time of firing

Tc : Temperature at time c

r1 : Rate (temperature units per minute) at which the temperature was rising during the 5-min period before firing

r2 : Rate (temperature units per minute) at which the temperature was rising during the 5 min.

The baseline that corrected temperature rise for each experiment is precisely identified and used, as will be shown later, in calculating the thermal properties.

15. After the last temperature reading, stop the motor, remove the belt and lift the cover from the calorimeter. Wipe the stirrer with a clean cloth and set the cover on the support stand. Lift the bomb out of the bucket; remove the ignition leads and wipe the bomb with a clean towel.

16. Open the knurled knob on the bomb head to release the gas pressure before attempting to remove the cap. This release should proceed slowly over a period of not less than one minute to avoid entrainment losses. Examine the interior of the bomb for soot or other evidence of incomplete combustion. If such evidence is found, the test will have to be discarded.

2.9 Energy Content of MSW

Energy content of MSW is the net calorific value of waste. It is the heat produced by a unit quantity of waste, at constant volume and at constant pressure of one atmosphere. It is assumed that all the water in the waste remains in the form vapors. The energy content of MSW can be determined by means of an oxygen bomb calorimeter under controlled conditions. The calorific value is computed from temperature observation made before and after combustion, making proper allowance for thermometer and thermo chemical corrections.

2.10 Calculation Energy Equivalent (Standardizing the Calorimeter)

The Energy Equivalent Factor, the term “standardization” as used here denotes the operation of the calorimeter with a standard sample from which the energy equivalent or effective heat capacity for the system can be determined by substituting in the equation 2.7.

$$W = \frac{Hm + e_1 + e_3}{\Delta t} \dots\dots\dots (2 . 7)$$

Where:

W: Energy equivalent of the calorimeter in calories per °C.

H: Heat of combustion of the standard benzoic acid sample (6318 cal/ gram).

m: Mass of the standard benzoic acid sample in grams

Δt: Net corrected temperature rise in °C.

e₁: Correction for heat of formation of nitric acid in calories.

e₃: Correction for heat of combustion of the firing wire in calories.

In order to achieve this goal, the work was consisted of six experiments in order to obtain calibration with high precision and which will be reflected on the results, the values of factor and the results are shown in the (table 2. 2).

Table 2.2: Values of energy equivalent factor experiments

Benzoic Acid	BA. 1	BA. 2	BA. 3	BA. 4	BA. 5	BA. 6
ΔT C°	2.61592	2.647261	2.633096	2.649292	2.648887	2.643534
Mass of sample (g)	1	1.01	1	1.01	1.01	1.01
wire used (cm)	9.63	8.4	8.9	9.1	8.8	9.2
Energy Equivalent Factor.	2427.73	2421.86	2411.43	2420.54	2420.72	2426.05

From the results obtained in the preceding table the average energy equivalent factor, standard deviation, and percent of error in (table 2.3), all the information and values needed for calculations in annex 3 can be seen .

Table 2.3: Average of energy equivalent factor, standard deviation

Heat Content of Calorimeter			
Average (kJ/kg)	St. Dev. %	Manufacturer range (kJ/kg)	Error %
2421.39	5.70	2426 ±15	-0.190%

2.11 Calculation of the Heat of Combustion

To calculate the calorific value and after the completion of each experiment, the following data should be available at the completion of a test in a Parr bomb calorimeter 1341 in reference to the guidelines (Technical Manual, 1982). The experiments nomenclatures are the following:

Period after time

c_1 : Milliliters of standard alkali solution used in the acid titration.

c_2 : Percentage of sulfur in the sample.

c_3 : Centimeters of fuse wire consumed in firing.

W: Energy equivalent of the calorimeter, determined under standardization.

m: Mass of sample in grams.

Compute the net corrected temperature rise Δt , by using equation 2.6.

2.11.1 Gross Calorific Values.

Compute the Gross Calorific Value of combustion, (GCV), in calories per gram by substituting in the following equation 2.8:

$$GCV = \frac{\Delta tW - e_1 - e_2 - e_3 - e_4}{m_s} \dots\dots\dots (2.8)$$

Where:-

W : Energy equivalent of the calorimeter in °C identified by standard tests

GCV : Heat of combustion of mass sample in cal/g, gross calorific value.

m_s : Mass of sample in grams.

Δt : Net corrected temperature rise in ° C.

e_1 : Correction in calories for heat of formation of nitric acid (HNO_3)
c1 if 0.0709N alkali was used for the titration.

e_2 : Correction in calories for heat of formation of sulfuric acid (H_2SO_4)
(13.7) (c_2) (m).

e_3 : Correction in calories for heat of combustion of fuse wire
(2.3) (c_3) when using Parr 45C10 nickel chromium fuse wire.

e_4 : Correction in calories for heat of combustion of benzoic acid sample
(6318 cal/ gm) (m_{BA}) cal.

2.11.2 Calorific Values

Measuring the calorific values (heat of combustion) is done by using a constant volume oxygen bomb calorimeter for all samples according to ASTM E144 – 2006 the (table 4.12) and (fig.4.13) showing the results of calorific value (Dry) MJ/kg.

Gross Calorific Values (GCV)

The heat of combustion is the energy released as heat when a compound undergoes complete combustion with oxygen under standard conditions. The chemical reaction is typically a hydrocarbon reacting with oxygen to form carbon dioxide, water, and heat. The measured calorific value is called the Gross Calorific Value of the Higher Caloric Value and it reflects the heat of combustion. Identification of GCV is done using the constant volume oxygen bomb calorimeter in accordance to ASTM E144 (2006). Measured values for MSW different samples are tabulated in (table 4.12) and shown in (figure.4.14) and can see all the information and values needed for calculations normal compound samples in annex 4.

Net Calorific Values (NCV)

The determination of the net calorific value (NCV) is done by considering the as-received (AR) waste with its moisture content. Thus by subtracting the heat of vaporization of the water from the gross calorific value (higher heating value), the lower values could easily be identified by equation 2.9.

$$NCV = GCV \times \left(\frac{100 - MC}{100} \right) \dots \dots \dots (2.9)$$

Chapter III

3.1 Results and Discussions

The experimental work carried out the following verified standards of ATSM. The following results are the true values identified for the samples collected from the study area and are for the MSW different combustible streams.

3.2 Composition of MSW by weight

In table (3.1) the weight composition of MSW is identified experimentally on-site and is listed and is presented in detail in annex 5.

Table 3.1: Mean weight composition of MS in the study area

Waste Type	Average June Kg	Average July Kg	Average September Kg	Average October Kg	Average November Kg	Average (all) Kg
Organic and food wastes	161.9	164.0	160.2	177	160.9	164.8
Plastics	32.5	29.0	29.1	26.7	27.7	29.0
Paper and cardboard	11.6	10.5	10.1	15.8	13	12.2
Glass	1.7	2.8	2.1	2.9	2.4	2.4
Metals	3	5.7	3.1	4.5	3.3	3.9
Textiles	16.6	12.8	13.7	11.9	12.3	13.5
Wood	2	2.6	2	2.8	2.5	2.4
Others	26.2	36.2	39.2	38.7	36.7	35.4

By analyzing the data gathered, it is clearly that the trends of SW disposing show good agreements over the five months during which on-site sampling was performed.

The compositions of MSW constituencies are identified in (figure 3.1). The figures indicate that the bulk generated waste is organic and specifically food waste which comprises over 60% of total MSW by weight. Plastic waste is the second which certainly indicates the overburden resulted from the baking and plastic bottles.

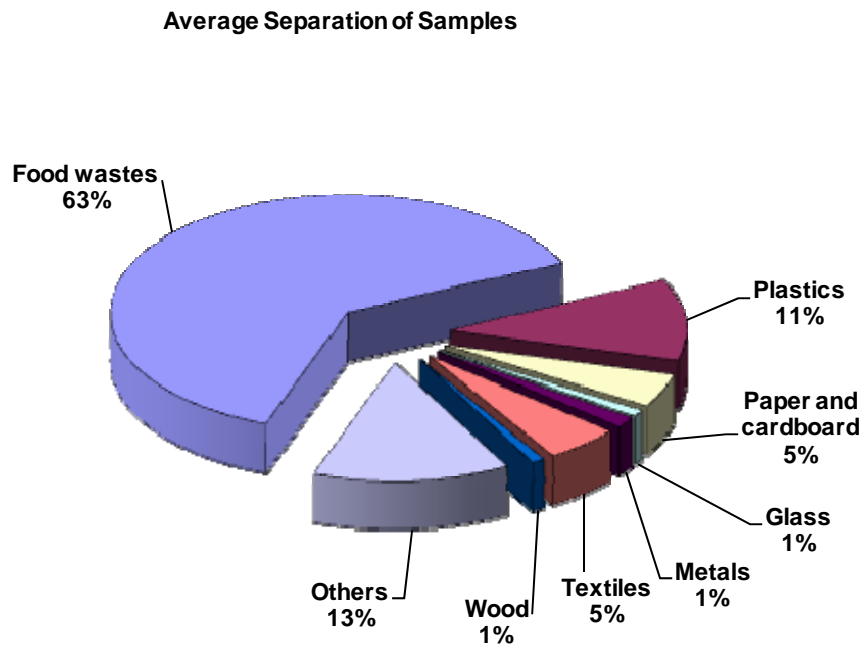


Fig. 3.1: MSW distribution percent by weight- study area

The results showing the composition of MSW agree well with figures shown in references. A field study conducted by International Management Group (International Management Group, 2010) during January 2010 for Hebron and Bethlehem cities indicated that waste composition is: 56.9 % food waste, 14.8% plastics and rubber, 6.9% paper and cardboard, and 4.3% textiles for the Hebron city.

Other older survey studies of the composition of MSW in the PNA showed that ranges for MSW are: 60-70 % food waste, 7-10 % paper/cardboard, 5-10 % plastic, 3-6 % glass, and 2- 3 % metals (Khatib, I., 2009 and Al-Hmaid, M. 2002).

In other neighboring countries of same traditions and income, the composition of MSW is nearly the same. In Jordan capital of Amman city, the range of food waste fraction is 65%-77% (Abu Qadais H. et al., 2007). When looking at developing countries in Southeast Asia, the composition of MSW agree well with that found for the PNA. E.g. in Indonesia food waste comprises 62% of the total generated MSW (Yen, U. et al., 2009). In some least developed countries such as Bangladesh, the composition MSW food waste comprises more that 70% of the generated MSW (Alamgir, M. et al., 2007).

3.3 The MSW density

The densities of MSW streams are shown in table (3.2). These results reflect normal values. The total average density agrees with a survey study done by (Al-Khateeb, A. 2009) for the West Bank area which showed that MSW ranges from 114.4 to 173 kg/m³.

Table 3.2: Average and range density of waste types

Waste Types	Weight kg	Volume m ³	Average Density kg/m ³	Range Density kg/m ³
Food wastes	82.89	0.267	310.45	307.3 – 314.1
Paper, Cardboard	6.15	0.1256	48.96	46.2- 50.3
Plastics	10.78	0.0785	137.3	133.8 – 140.4
Textile	2.6	0.0207	125.6	126.7 – 120.1
Wood	1.16	0.00785	147.77	145.3 – 149.2
Glass	1.25	0.01256	99.5	97.6 – 101.3
Metal	2.94	0.0157	187.26	185.1 – 190.2
Others	11.26	0.0611	184.28	179.6 – 188.8
Total	110.03	0.589		

The density of as-received MSW could be larger depending on the water content and therefore in some countries of low income average density of MSW may reach an average of 150 to 400 kg/m³ (Cointreau, S. 1982, Pollution Control Department, 1998)

3.4 Proximate analysis

Proximate analysis is performed for five types of MSW streams which are considered combustible. These are food waste, plastic, paper and cardboard, wood and textile. Properties identified are the moisture content, the volatile matter, the ash content, and the computed fixed carbon content.

3.4.1. Moisture Content:

Moisture contents for all streams' samples identified based on ASTM - D4843 (2009) are tabulated in (Table 3.3). Those samples are collected over the period June –November 2010. Same table contains maximum and minimum and average experimental values. For all values identified experimentally ranges of standard deviation is acceptable.

Table 3.3: Moisture content values through June –November 2010

June / Summer	Moisture Content %				Ave.	Stand. Dev.
Food wastes	62.3	63.4	61.2	63.1	62.5	0.983
Paper, cardboard	7.1	8.0	7.3	7.8	7.55	0.420
Plastics	1.9	2.1	2.0	2.2	2.05	0.129
Textile	6.6	6.9	6.7	7.2	6.85	0.264
Wood	13.7	13.4	13.9	14.3	13.825	0.377
July/ Summer						
Food wastes	59.1	57.7	58.9	58.56	0.757	
Paper, cardboard	6.0	5.4	5.8	5.733	0.305	
Plastics	1.7	1.1	1.5	1.433	0.305	
Textile	4.9	4.6	5.2	4.9	0.300	
Wood	11.2	9.7	10.8	10.56	0.776	
September /Autumn						
Food wastes	63.2		61.2	62.2	0.141	
Paper, cardboard	8.1		7.7	7.9	0.283	
Plastics	2.3		2.1	2.2	0.141	
Textile	7.4		7.1	7.25	0.212	
Wood	14.1		13.9	14	1.414	
October/ Autumn						

Food wastes	64.1	62.1	61.4	62.53	1.401
Paper, cardboard	8.2	7.9	7.5	7.866	0.352
Plastics	2.4	2.1	1.9	2.133	0.252
Textile	7.6	7.3	6.9	7.266	0.352
Wood	14.3	14.0	13.6	13.96	0.352
November /Autumn					
Food wastes	75	75.3	65.3	75.15	0.212
Paper, cardboard	14.2	14.6	8.6	14.4	0.283
Plastics	4.2	4.4	2.8	4.3	0.141
Textile	15.3	15.7	7.7	15.5	0.283
Wood	28.5	28.8	14.5	28.65	0.212
	Rainfall				

It should be noted here, that the study period represents the summer and autumn seasons. It is found that during the whole study period figures agree well with each other, however, in November and over two on-site sampling days, values for moisture content recorded higher values than the rest. This is due to the fact that these were rain days and as samples in the dumpsite, which is an open space place, rain water mixed with wastes and thus increased their moisture contents. By excluding rainfall days, average moisture contents are calculated and which shows in histogram chart (Figure 3.2).

Moisture Content

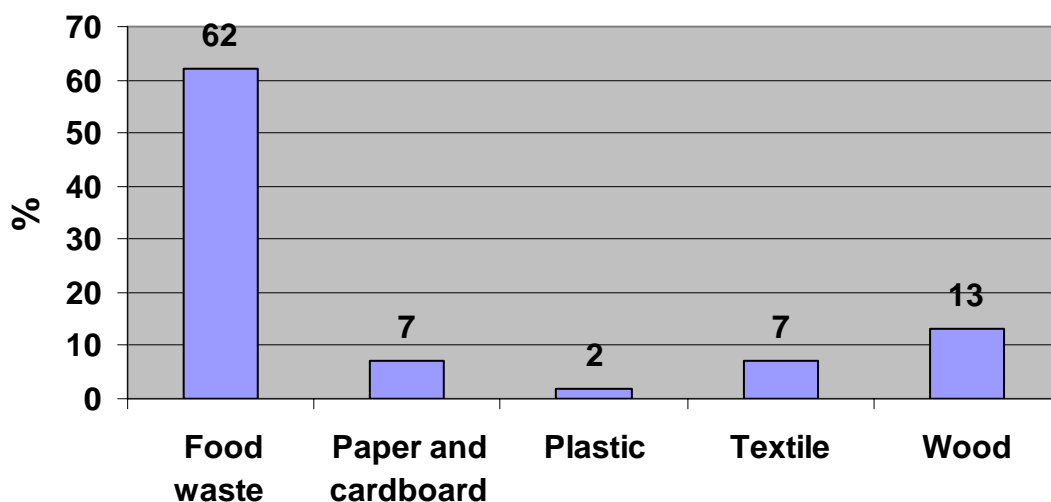


Fig. 3.2: Average moisture content of waste types

The amount of moisture in the combustible substance is highly important in energy conversion, as the moisture is mainly water which is not combustible but should be evaporated. The evaporation of water requires amount of heat energy (latent heat for evaporation) and thus the total energy that could be converted will be lower by the amount of required latent heat for evaporation. In this case, organic waste that contains a percentage of 62 of its weight as moisture will give less energy when incinerated in its wettable state. On the other hand plastic has a 2% moisture content, which means less energy will be required for evaporation. To distinguish between combustible wastes, wet or dry, both gross and net calorific values quantify the amount of heat recovered in case of moisture existence or non-existence respectively. To ensure minimal moisture content, special sealed containers should be used at collection points. In winter, containers should be sealed in a way not to allow rain to mix with wastes.

This situation identified for moisture content showed good agreements with studies performed. The World Bank technical guidance report for MSW incineration (1999) showed that optimal incineration possibility could be attained for MSW with moisture content of 66% for food waste, 29% for plastics, 33% for textile, and 47% for paper and cardboard, and 35% for Wood.

In a study done for assessing incineration of MSW for Kuala Lumpur in Malaysia results for moisture content are in the range of 60-70 % for food waste, 6-15% for paper and cardboard, 22.5% for textile, and 10 % for plastics (Mark, F. 1994).

3.4.2. Volatile Matter:

Volatile matter is determined on dry basis for all samples according to (ASTM E 897-88-2004) under carefully controlled conditions in order to obtain the most accurate practical results of the experiments. The results are shown in (figure 3.3). Figures agree well with values found in developing countries, e.g. 21.4% for food waste, 75.9% for paper and cardboard and, 95.8 for plastics (Tchobanoglous, G. et al., 1993). It should be noted that volatile matter reflect the combustibility of the SW and that plastic is clearly the most combustible stream when compared with the other streams considered.

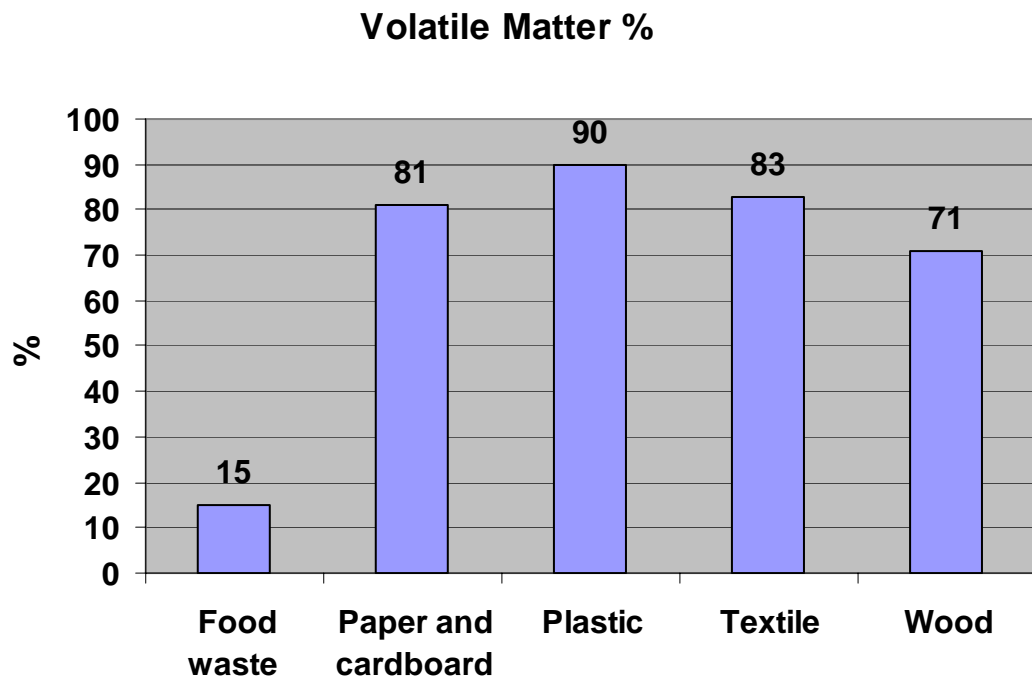


Fig. 3.3: Average VM of waste types

Volatility of wastes is a measure of the flammability and it means that a higher volatility, a better energy conversion. From the results shown, less volatility is associated with the food waste, this because of the moisture content that is higher than in other streams. Again, to increase volatility, it is important to decrease the moisture content. Whenever the percentage of volatile matter is higher in the waste stream, the rate of disposal of the material and converted to more energy, can observed in the plastic which has the highest percentage 90% of VM and the highest value in the GCV up to 40 MJ/kg.

3.4.3. Ash Content:

As content of samples are identified using the ASTM E 830-87 (2004). The results of the experimental work for ash contents are presented in (figure 3.4). Again, these values are in good agreement with other referenced values. The total average amount of ash content on dry basis for the five streams is 6.4%. This figure agrees well with figures issued by the World Bank report on MSW incineration. In this report, ash content were found to be 13.3% for food waste, 7.8% for plastics, 4% for textile, 5.6% for paper and cardboard, and 5.2% for wood 5.2% (World Bank, 1999). This is also the case for other studies (Mark, F. 1994, Alam, J. et al., 2007) done for developing countries.

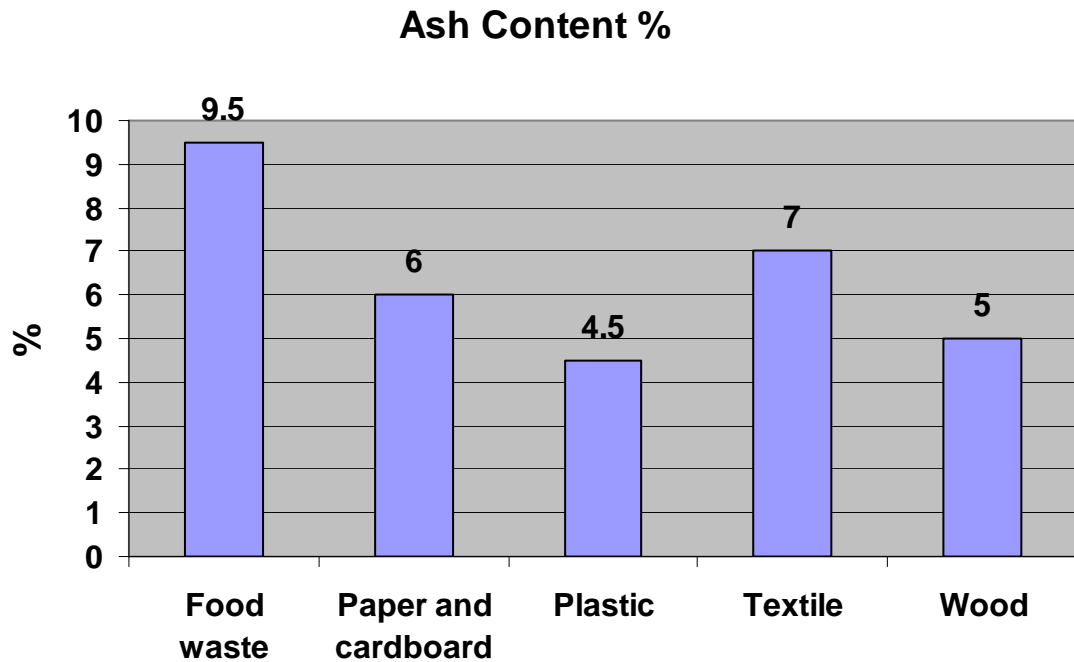


Fig. 3.4: Average ash content of waste types

Ash content measures the quality of incineration; however, it strongly dependant on moisture content in the waste. E.g. food waste has higher ash content because of its higher moisture content.

3.4.4. Fixed Carbon:

The Fixed Carbon (FC) in percentage can easily be computed based on the approximate analysis that is done for previous properties. Values of fixed carbon presented in (Figure 3.5).

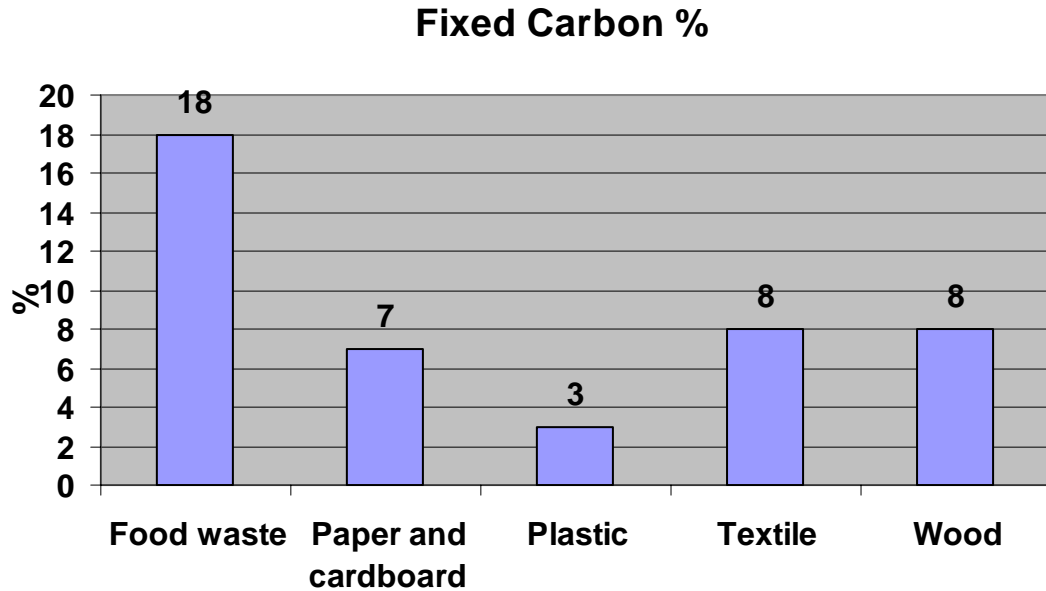


Fig. 3.5: Average fixed carbon of waste types

Fixed carbon is the net results of subtracting 1 unit of weight from proportions of the unit weight that represent the moisture content, ash, and volatile matter. It means how much carbon fixed in a 1 unit of weight after evaporating the moisture and burning the volatile matter and leaving ash unburned.

To summarize all results obtained, Table 3.4 shows the dependency of quantities obtained on each proximate analysis property. All relevant results are presented in annex 6

Table 3.4: Values of MC, A, VM and FC for each waste streams

Proximate Analysis					
Waste Type	MC (%)	VM (%)	A (%)	FC (%)	%
Food waste	0.6177	0.1543	0.0493	0.1787	100

	0.6177	0.1671	0.0370	0.1782	100
Paper and cardboard	0.0734	0.8110	0.0460	0.0697	100
	0.0734	0.7958	0.0552	0.0756	100
Plastics	0.0201	0.9009	0.0490	0.0301	100
	0.0201	0.9151	0.0392	0.0257	100
Textile	0.0662	0.8302	0.0281	0.0755	100
	0.0662	0.8244	0.0375	0.0719	100
Wood	0.1318	0.7192	0.0706	0.0784	100
	0.1318	0.7177	0.0794	0.0711	100

The values that are obtained will be used to compute the net calorific values and when integrated with chemical properties of the wastes, i.e. chemical elements content in each waste stream, assessment of energy content could also be performed without the need for indentifying gross calorific values.

3.4.6. Calorific Values:

The heat of combustion is the energy released as heat when a compound undergoes complete combustion with oxygen under standard conditions. The chemical reaction is typically a hydrocarbon reacting with oxygen to form carbon dioxide, water, and heat. The measured calorific value is called the Gross Calorific Value. Identification of GCV is done using the constant volume oxygen bomb calorimeter in accordance to ASTM E144 (2006). Measured values for MSW different samples are shown in (Figure.3.6) and tabulated in annex 7.

Calorific Values

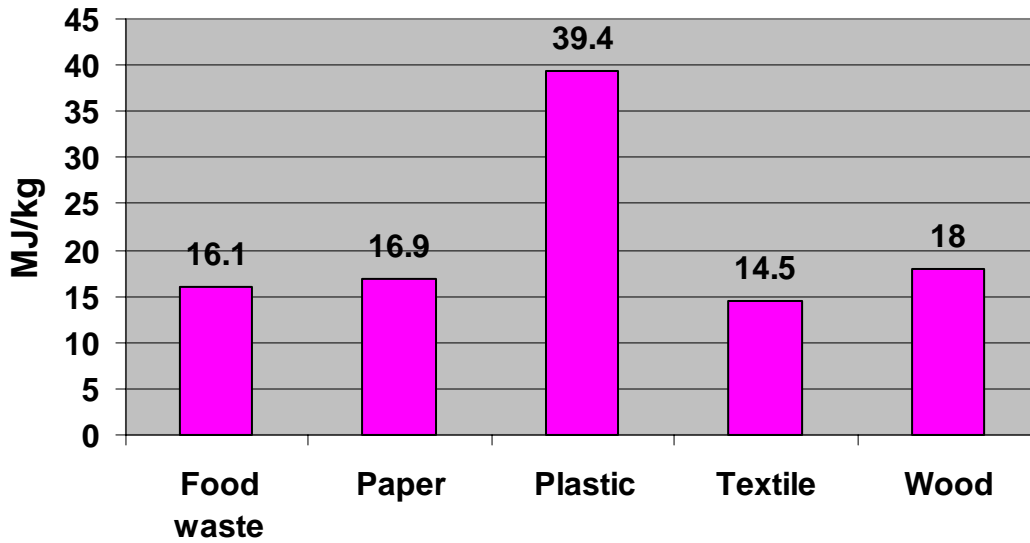


Fig. 3.6: Average Gross Calorific Values for each waste streams

The experimental values of thermal properties agree well with values found in several countries. It is obvious that plastic heat content is the largest and that this constituent is the optimal fuel when considering heat recovery of MSW.

The Values that are identified in developing countries are identical. In Malaysia the heating values food waste is 15.85 MJ/kg, for plastic 31 MJ/kg and for paper 16 MJ/kg (EPA 1995, Rotter, S. 2003, Technobanoglous, G, 2002). In Ghana, food waste has GCV of the range 16.28-17.5 MJ/kg, paper and cardboard 16.82 - 19.23 MJ/kg, textile 16.11 - 16.97 MJ/kg (Fobil, J. 2002). The World Bank technical guidance report for MSW Incineration in (1999) showed that average GCV for food waste is 17 MJ/kg, for plastics 39 MJ/kg, for textile 20 MJ/kg, for paper and cardboard 16 MJ/kg, and for wood 17 MJ/kg (World Bank, 1999). These values typically are almost the same as the experimentally identified values in the context of this research study. Other similar values are reported elsewhere, e.g. EPA (1995), Rotter (2003), O'Leary, P (1987) and McGRAW-HILL, (2002).

Net Calorific Values (NCV)

The determination of the net calorific value (NCV) is done by considering the as-received (AR) waste with its moisture content. Thus by subtracting the heat of vaporization of the water from the gross calorific value (higher heating value).

In the table (3.5) below the lower calorific values for all samples are calculated using the identified gross values.

Table 3.5: GCV, Stan. Dev., MC, NCV as received

Sample	GCV (Dry) MJ/kg	Stand. Dev.	MC (%)	NCV (AR) MJ/kg
Food Waste 1	15.83692	0.24	62.22	5.98319
Food Waste 2	16.31247		62.22	6.16285
Food Waste 3	16.15093		62.22	6.10182
Paper and Cardboard 1	17.34065	0.34	8.69	15.83375
Paper and Cardboard 2	16.92681		8.69	15.45587
Paper and Cardboard 3	16.65372		8.69	15.20651
Plastics 1	40.20840	1.8	2.12	39.35464
Plastics 2	37.30390		2.12	36.51181
Plastics 3	40.79070		2.12	39.92458
Textile 1	14.83278	0.25	1.10	14.66958
Textile 2	14.32014		1.10	14.16258
Textile 3	14.50804		1.10	14.34841
Wood 1	17.19552	0.73	1.59	16.92234
Wood 2	18.59117		1.59	18.29582
Wood 3	18.24089		1.59	17.95110

The Calculated lower calorific values for MSW streams agree also well with values found in Europe and Asia. In Ireland, MSW streams have lower calorific values of 3.98 MJ/kg

for food waste, 13.3 MJ/kg for paper, 33.3 MJ/kg for plastics and, 16.11MJ/kg for textile (Smith, A. 2001). This is the same for Malaysian MSW streams (Mark, F. 1994).

3.5 Energy Content in MSW

Assessing energy content in the MSW main streams brought promising figures when considering the amount of generated waste. Table (3. 6) shows energy content in 100 kg of MSW considering only combustible wastes that comprises 84.206% (or 84.206 kg out of 100 total weight). On dry basis, energy content more than 900 MJ. This figure is promising; however, the figure will drop when considering the energy conversion system and efficiency.

Table 3 6: Results use 100 kg of MSW streams

Component Basis 100 kg total weight (without metal and others)	Wet weight kg	MC %	Dry weight %	Dry weight kg	GCV kJ/kg	Energy Content kJ	NCV kJ/kg	Diff. Wet - Dry
Food waste	62.52	62	37.8	23.62	16100.1	380282.6	6082.6	0.00
Paper and cardboard	4.64	9	91.3	4.24	16973.7	71903.5	15498.7	0.00
Plastics	11.05	2	97.9	10.81	39434.3	426424.3	38597.0	0.00
Textile	5.10	7	93.2	4.75	14553.6	69171.9	13564.9	0.00
Wood	0.90	13	86.6	0.78	18009.2	14041.6	15601.1	0.00
Total	84.206			44.202		961823.96		0.00

The heating values for each stream show that the plastic is the stream with maximum energy content (GCV \approx 40 MJ/kg).

For the calculations of energy content we have excluded MSW stream which are noncombustible, i.e. glass, metal and others.

Assuming burning (incinerations) 84.2 kg of combustible waste, which forms 84.2% of total SW, will get about 2672 kwh (962 MJ) of energy will the produced which is promising, considers the amount of combustible waste generated in all Palestinian districts, a total of 4 million barrel of oil equivalent will be spored annually. This is huge amount of

energy source, which if in an efficient way utilized would be sufficient for producing energy needed for development activities, i.e heat for desalinating water.

3.5.1 Compound Samples:

In preparing compound sample of several substances at different rates as ratios resulting from the screening process so that the proportion of organic matter 50% in the first experiment and then increases to become (55, 60, 65, 70 %) and the rate of increase in organic material at the expense of other materials in proportion to its presence in the waste at the screening process with the exception of glass, metal and other materials.

Table 3.7: Calorific value of compound samples

	GCV (MJ/kg)	GCV (MJ/kG) for Mixed
Organic (55%)	20.37406	19.47104
Organic (60%)	20.28154	19.26771
Organic (65%)	19.4025	19.08716
Organic (70%)	18.22365	18.92002
Organic (75%)	18.17112	18.77658
Ave. CV. (Mixed)	19.29057	19.1045
Stand. Dev.(Mixed)	1.067706	0.275163

It was found that the calorific value in the composite sample equals approximately the calorific value in the amount of each of these materials separately as shown in (table 3.7) Enabling us to the burning of MSW without having to pay the extra cost in the process of sorting before the burning process and this is another additional advantage to the system.

Chapter IV

4.1 Conclusion

The characteristics analysis of MSW in Hebron city showed that solid waste is rich in combustible streams, forming over 80% of the generated solid waste based on the weights. This is typically the case in the developing countries and countries of low per capita. The waste proximate characteristics of streams' samples brought relevant values of moisture content (%), volatile value (%), fixed carbon and ash with low standard deviations. The results that are obtained for proximate analysis agree well with those found for similar countries. The Analysis of the heat recovery for the different streams' samples brought relevant results with minimal standard deviations. The average gross calorific values of food waste, plastics, paper and cardboard, textile and wood are found 16 MJ/kg, 39 MJ/kg, 17 MJ/kg, 15 MJ/kg, and 18MJ/kg respectively. These values are in good agreement with same reported in relevant references, including the comprehensive professional report published by the World Bank. The results of the experimental work which is done for identifying thermal properties of mixed-stream samples of different percentages compositions brought relevant results. The results that are obtained with minimal standard deviations for samples tested with an average 19.3 MJ/kg that well agrees with the computed 19.1 MJ/kg using identified pure samples' gross calorific values. This is a clear indication that shows the preciseness of the experimental work.

In the assessment of the heat recovery from a unit mass (100 kg) of the MSW comprised on composition of 84% combustible wastes, brought a promising result of 962 MJ, which could be converted into any other useful energy forms using MSW incinerator. This is an alternative source of energy that when utilized, impact on the environment, the natural resources and the public health , and as a result the solid waste dumpsites will be mitigated.

In view of the properties identified and based on the annual generated MSW, the total average of heat energy which is equivalent to 4 million barrel of oil energy could be recovered. Such a huge amount of heat energy may be utilized in different systems, i.e. desalinating seawater for. However, further studies need to be done on the energy conversion efficiencies and the technical and economical feasibilities of the energy conversion systems.

4.2 Recommendation

1. The results show that heat recovery of MSW is representing a potential, how ever, it is recommended to perform future analysis on the feasibility (technical and economical) of using Waste-to-Energy systems. If portion feasible, this will bring benefits is particular the reduction of waste dumped in dumping sites, this preserving the land.
2. The results show that the calorific value in the composite sample approximately equals the calorific value in the amount of each of these materials separately, Which means that it can burning of MSW without having to pay the extra cost in the process of sorting before the burning process and this is another additional advantage to the system.
3. The results show that the rain water mixed with wastes and thus increased their moisture contents, which require energy to dry before burning; to avoid this can be stored the waste in containers with covers especially in winter.

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Eng. Read Al-Ashhab, Department Director – Environmental and Health in Hebron Municipality / through period of research.

Annex 1.

Calibration of the bomb calorimeter:

Before conducting thermal testing for solid samples, the calorimeter should be calibrated by a sample of known calorific value according to manufacturer manual and guidelines.

The Energy Equivalent Factor “standardization” used here denotes the operation of the calorimeter with a standard sample from which the energy equivalent or effective heat capacity for the system can be determined. The energy equivalent factor represents the energy required to raise the temperature of the calorimeter one degree, usually expressed as calories per degree Celsius. This factor for the 1341 calorimeter with an 1108 oxygen bomb will usually fall within a range from 2410 to 2430 calories per degree Celsius, with the exact value for each installation to be determined by the user. This requires a series of at least four standardization tests (and preferably more) from which an average can be taken to represent. This will provide a factor which can be used with confidence in subsequent tests with unknown materials.

Parr bomb calorimeter uses a 1g Benzoic Acid has known calorific values of 6318 cal/g.

In the calibration of the device the following are identify

Task overview: Carry out at least four independent measurements of the benzoic acid standard and at least three independent measurements of the “unknown” sample.

Pellet preparation: Care must be taken to avoid overcharging the bomb must be realized that the peak pressure developed during combustion is proportional to the size of the sample and to the initial oxygen pressure. Pellet size should be limited to not more than 1.1 g.

1. Weigh out approximately 1.0 g of sample. Grind it in a clean mortar and pestel.
2. Carefully place it in the sample cup with tweezers.

Connect the ignition wire:

1. Measure out approximately 10 cm of wire and weigh it. It will also be necessary to weigh any unburned wire after combustion since this is an important factor in the calculations.
2. Set the bomb head in the support stand and attach the length of nichrome fuse wire as illustrated in (fig.3.14). A pair of tweezers may be helpful in attaching the wire to the electrodes. Insert the wire through each eyelet then slide each cap downward to complete the connection.

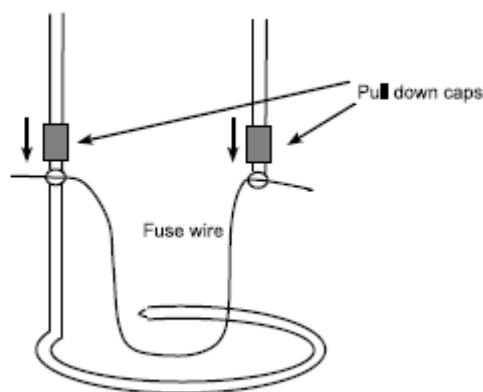


Fig. 3.14: Attachment of the nichrome ignition wire with ignition wire fixed on the electrodes

3. Place the sample cup (with the sample sitting in the center of the cup) in the cup holder and bend the ni-chrome wire in a V-shape. Position the wire so that it almost touches the surface of the pellet (about 1 mm separation). Figure. (3.15) illustrates the proper installation and sample placement. Make sure that the wire does not touch the cup.

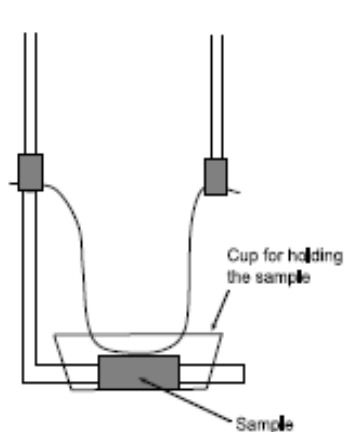


Fig. 3.15: Schematic of the sample support stand.

Note positioning of the ignition wire (about 1 mm from the sample but not touching it).

Liquids in the bomb: Passé 1.0 ml of deionized water into the bomb to absorb the oxides of nitrogen formed from nitrogen present in the oxygen mixture. (Halpern, A. 2006).

Closing the bomb assembly:

1. Care must be taken not to disturb the sample when sealing and charging the bomb. Slide the head assembly into the bomb cylinder, screw open the vent cap on the head assembly to allow air to be expelled, and push the head down as far into the cylinder as it will go.
2. Close the vent cap tightly. A tight seal is required to prevent oxygen leaks.
3. Check the circuit with an ohmmeter. If the resistance is too large ($\gg 100 \Omega$), open the bomb and check the wiring.

Install the oxygen connection:

1. Carefully secure the bomb in the bench clamp.
2. Slip on the oxygen tank connection hose to the pin on the head assembly.

Fill the bomb:

1. Open the oxygen tank valve. Open the regulator valve slowly and watch the gauge as the bomb pressure rises to the desired filling pressure (25 – 35 atm). Once this pressure is reached, close the control valve and then the tank valve.
2. Use the quick-release valve to quickly remove the oxygen tank connection to minimize oxygen escape. Slight leakage is normal but continuous leakage is a problem.

Operating the calorimeter:

1. Remove the lid and place it on the ring stand. Check to see that the bucket is resting properly in the jacket, noting the four pegs on the bottom of the jacket, which hold the bucket in place.
2. Carefully place the charged bomb in the bucket, noting that it rests on the raised circular area on the bottom of the bucket.
4. Connect the ignition wire to the terminal socket on the bomb head. Prepare 2 L of water that is between (19-21) °C. Fill the bucket with the 2 L of water. Be careful not to spill it.
2. Set the cover on the jacket. The screw attached to the lid fits into the screw hole in the ledge of the jacket.
5. Turn the stirrer by hand to be sure that it runs freely, and then slip the drive belt onto the pulley. If the belt does not work properly, rubber bands can be used.
6. Place the thermometer in the support and then attach the thermometer support carefully to the calorimeter (screws into lid). Adjust the rubber washer on the thermometer so that the bulb does not touch the bottom of the bucket.
7. Connect the two lead wires on the ignition unit to the calorimeter. Do not press the firing button unless the lead wire inside the jacket is connected to a bomb.

8. Let the stirrer run for 5 min. to reach equilibrium. At the end of this period start the timer, and read and record the temperature at one-minute intervals for 5 min. At the start of the sixth minute stand back and fire the bomb by pressing the ignition button and holding it down for about 5 s (until the light goes out).
9. The temperature should start to rise within 15-20 s of firing. Take the first temperature reading at 30 s and continue to take temperature readings every 15 s for a period of 3 min.
10. After this, three-minutes period record the temperature to the nearest tenth (ca. 0.002 °C accuracy) with the aid of the reading lens at one-minute intervals until the difference between successive readings is zero (or perhaps becomes negative). This will take approximately five minutes. Accurate time and temperature observations must be recorded to identify certain points needed to calculate the calorific value of the sample. Usually the temperature will reach a maximum and then drops very slowly.
11. After the last temperature reading, turn off all the electrical connections, remove the drive belt, and place the cover in support ring. Remove the ignition wire from the bomb, lift the bomb out of the bucket and wipe off any excess water. Open the valve cap and discharge the bomb in the hood. Unscrew the cap, lift the head out of the cylinder, and place it on the support stand.
12. Weigh any unburned fuse wire still attached to the electrodes and possible pieces of molten wire. When analyzing your results, you will need to subtract this weight from the total fuse wire burned. Examine the interior of the bomb for soot or other evidence of incomplete combustion. If such evidence is found the test will have to be discarded.

Annex 2: Temperature – Time Relationship and data.

Fig.1-10 illustrates Temperature – Time Relationship for Calorimetric Tests.

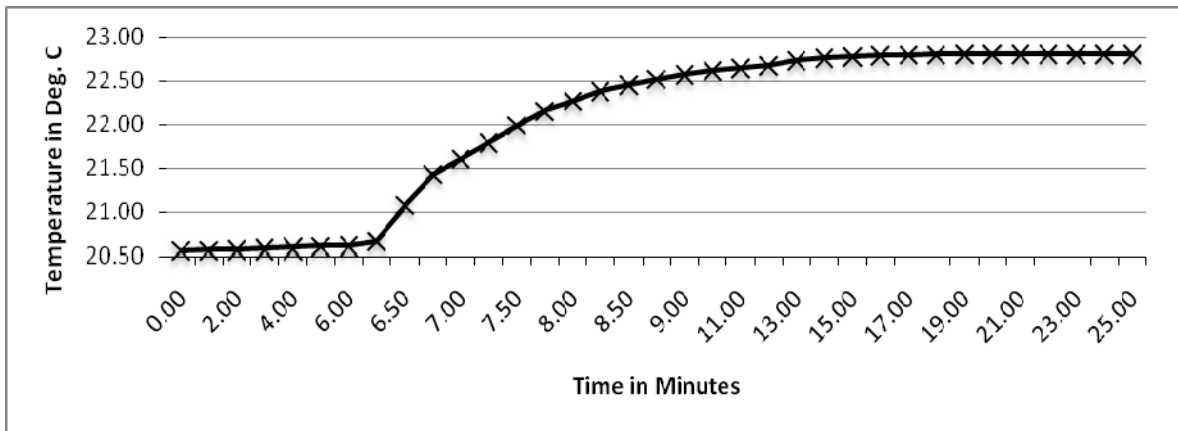


Fig. 1 Temperature – Time Relationship for Calorimetric Testing of (Food waste)

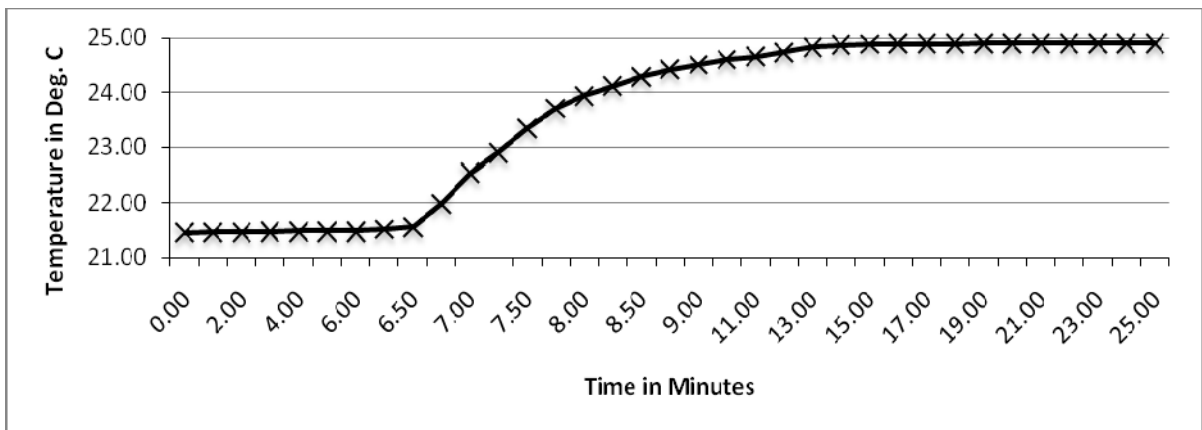


Fig. 2 Temperature – Time Relationship for Calorimetric Testing of (Plastic pellet sample)

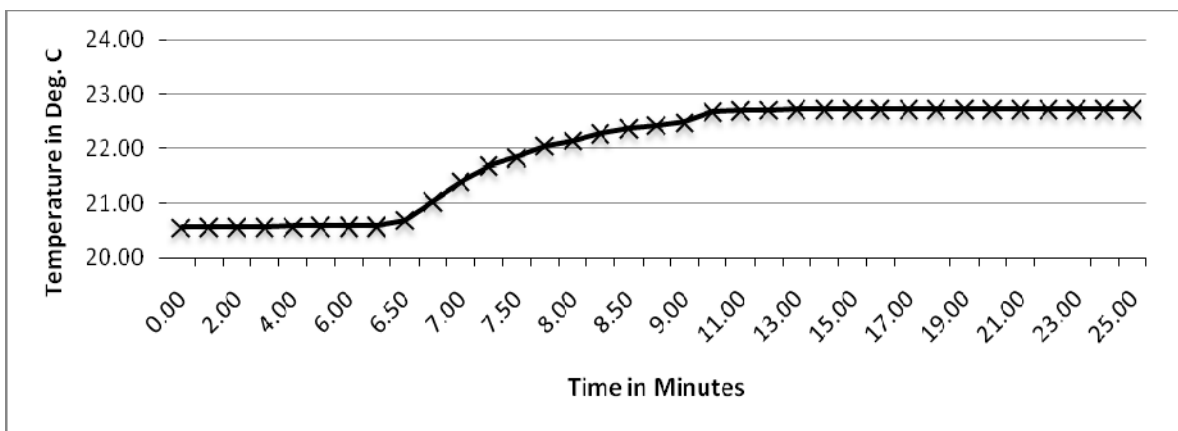


Fig.3 Temperature – Time Relationship for Calorimetric Testing of (Paper pellet sample)

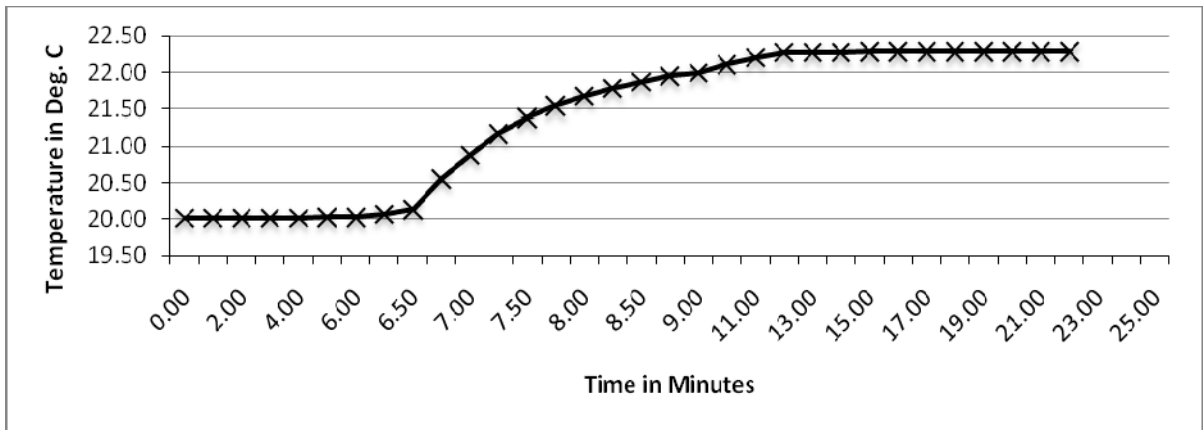


Fig.4 Temperature – Time Relationship for Calorimetric Testing of (Textile pellet sample)

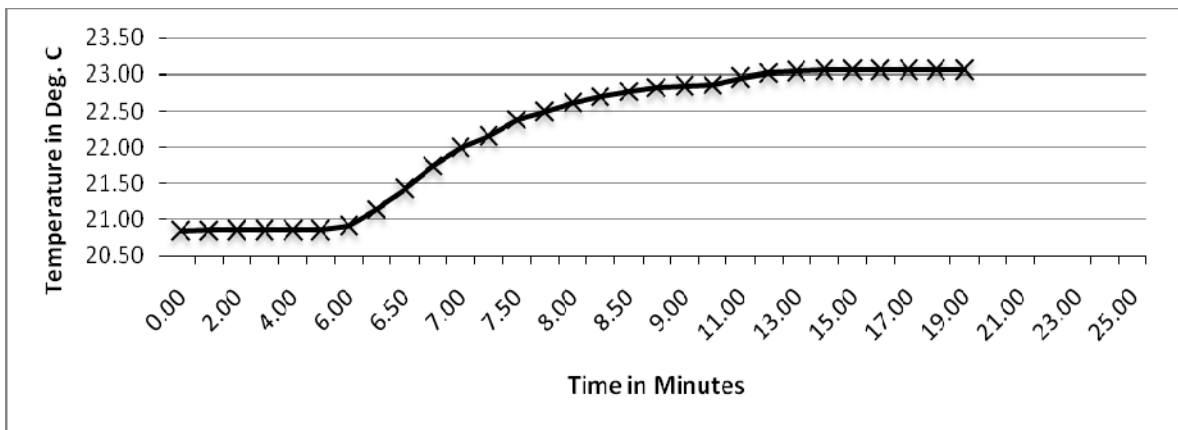


Fig. 5 Temperatures – Time Relationship for Calorimetric Testing of (wood pellet sample)

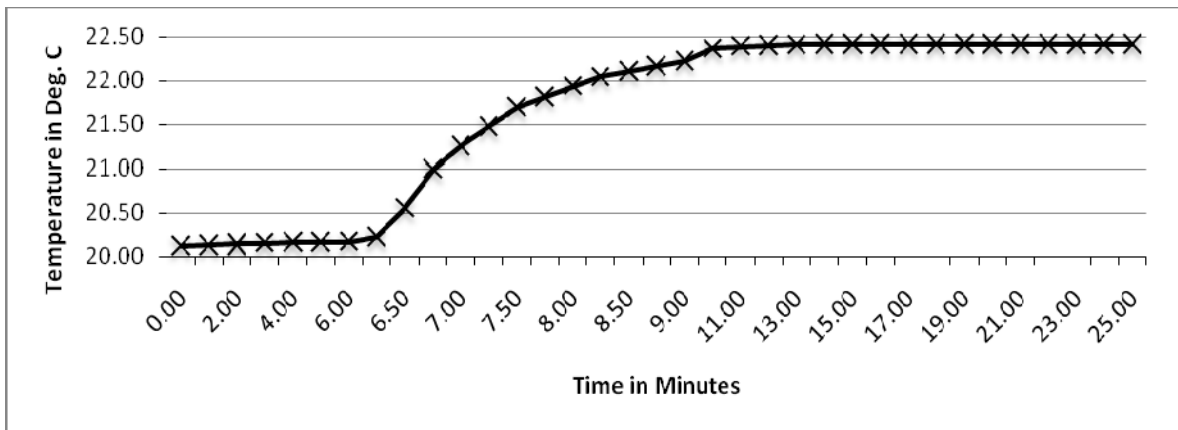


Fig. 6 Temperature – Time Relationship for Calorimetric Testing of (Organic (55%) pellet sample)

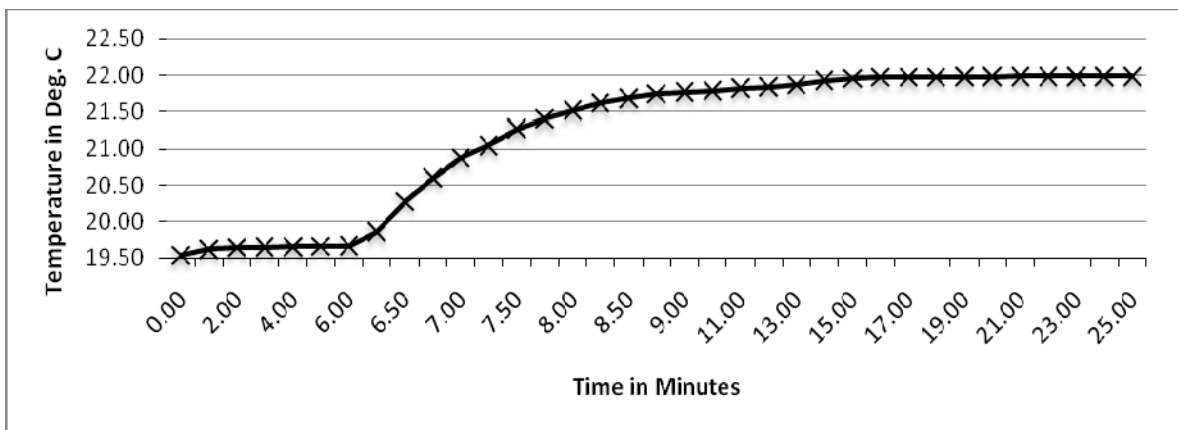


Fig. 7 Temperature – Time Relationship for Calorimetric Testing of (Organic (60%) pellet sample)

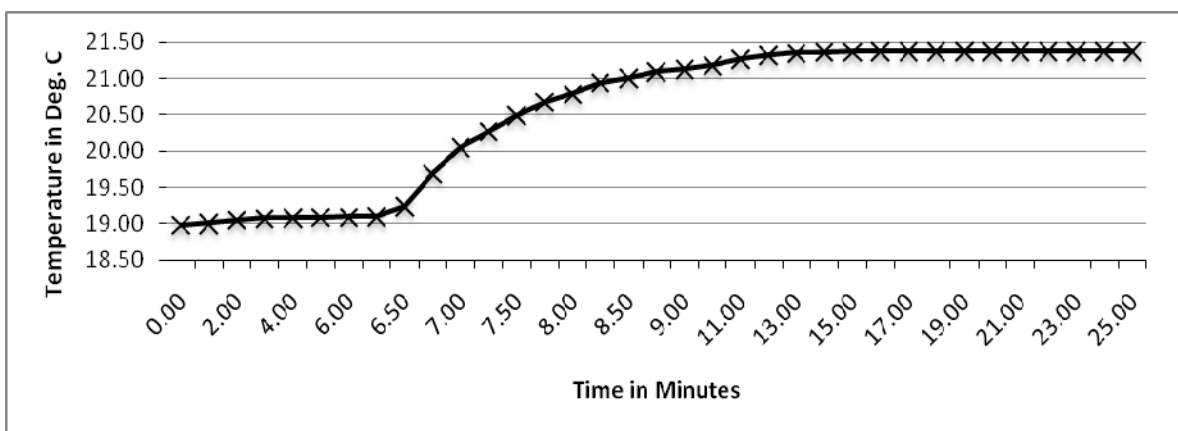


Fig. 8 Temperature – Time Relationship for Calorimetric Testing of (Organic (65%) pellet sample)

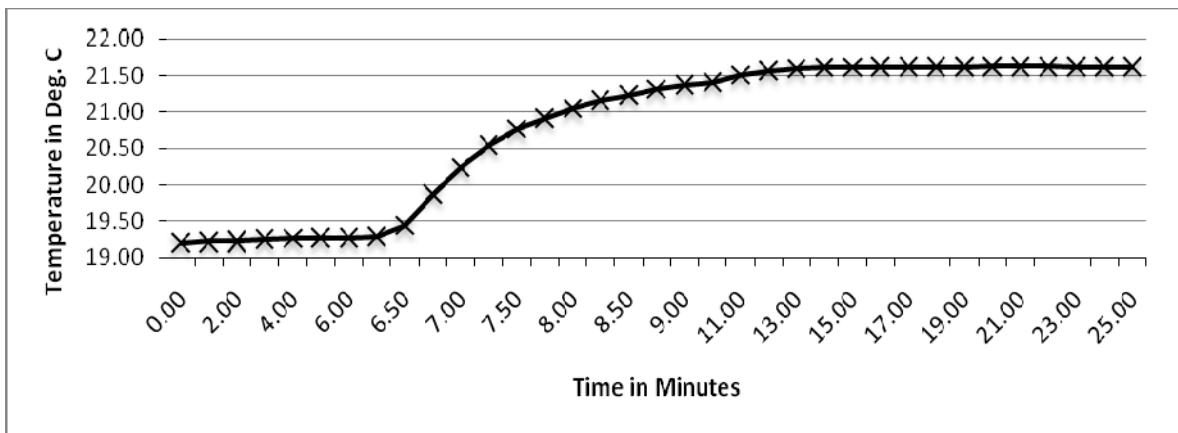


Fig. 9 Temperature – Time Relationship for Calorimetric Testing of (Organic (70%) pellet sample)

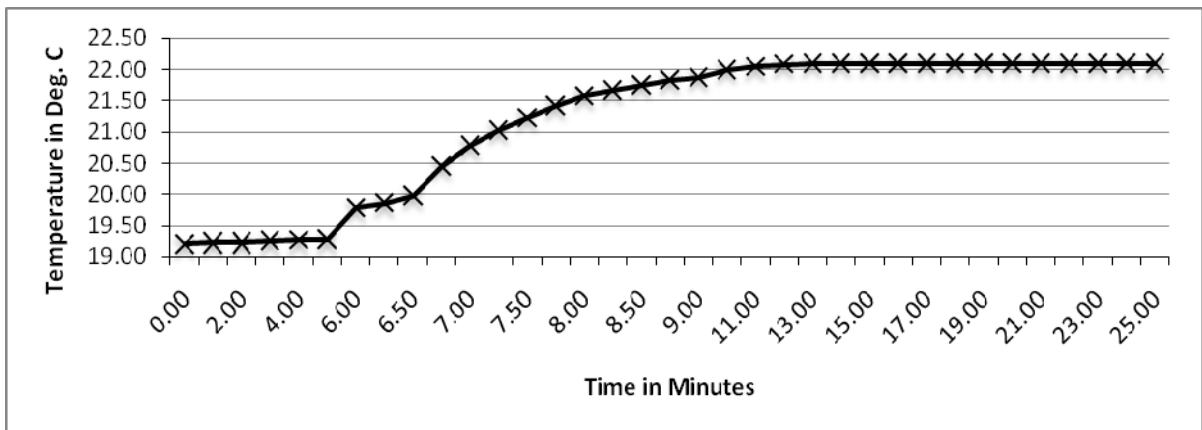


Fig. 10 Temperature – Time Relationship for Calorimetric Testing of (Organic (75%) pellet sample)

Annex 3: Specific information to calculate the equivalent factor.

Table 1 contains General information's that needed to calculate equivalent factor for calibration samples.

Sample	e 1 HNO ₃ Calories	e 2 H ₂ SO ₄ Calories	e 3 Wire used Calories	m B.A g	m Sample g	m Total g
Calibration 1	5.8	4.8	22.149	1.00	00	1.00
Calibration 2	5.8	5	19.32	1.01	00	1.01
Calibration 3	6	4.8	20.24	1.00	00	1.00
Calibration 4	5.7	4.9	20.93	1.01	00	1.01
Calibration 5	5.8	5	20.24	1.01	00	1.01
Calibration 6	6	5	21.16	1.01	00	1.01

Annex 4: Specific information to calculate the Calorific Values.

Table 1 contains General information's that needed to calculate GCV for food waste, plastics, paper and cardboard, textile and wood samples

Sample	e 1 HNO ₃ Calories	e 2 H ₂ SO ₄ Calories	e 3 Wire used Calories	m B.A g	m Sample g	m Total g
Food wastes 1	10.2	3.96	21.3	0.54	0.49	1.03
Food wastes 2	10.6	3.84	19.32	0.53	0.50	1.03
Food wastes 3	10.1	3.92	20.01	0.53	0.50	1.03
Plastics 1	11.3	8.04	20.01	0.52	0.49	1.01
Plastics 2	12.1	8.7	20.93	0.52	0.48	1.0
Plastics 3	11.2	7.86	21.39	0.52	0.49	1.01
Paper and cardboard1	5.4	3.96	20.01	0.49	0.43	0.92
Paper and cardboard2	6.8	4.2	20.70	0.50	0.50	1.0
Paper and cardboard3	6.4	3.7	20.01	0.51	0.50	1.01
Textiles1	7.3	5.04	19.09	0.48	0.47	0.95
Textiles2	8.1	6.1	20.24	0.50	0.49	0.99
Textiles3	6.2	5.6	19.78	0.48	0.48	0.96
Wood1	11.4	8.64	19.09	0.51	0.47	0.98
Wood2	10.6	9.25	20.01	0.41	0.57	0.98
Wood3	10.8	8.8	20.93	0.50	0.48	0.98

Table 2: contains general information that needed to calculate GCV for all compound samples with different percentages.

Compound Samples		Organic	Plastics	Paper	Textiles	Wood
Sample 1	77% from initial separate 8 categories	55	11.2	4.8	5	1
	% of 5 categories	71.43	14.54	6.24	6.49	1.3
	m = 0.5 g	0.3572	0.0727	0.0312	0.0325	0.0065
	m BA= 0.47 g	e 1 = 7.3	e 2 =3.36	e 3 =21.16		
Sample 2	82% from initial separate 8 categories	60	11.2	4.8	5	1
	% of 5 categories	73.17	13.66	5.85	6.1	1.22
	m = 0.5 g	0.3658	0.0683	0.0293	0.0305	0.0061
	m BA= 0.5 g	e 1 = 13.6	e 2 =4.8	e 3 =19.32		
Sample 3	87% from initial separate 8 categories	65	11.2	4.8	5	1
	% of 5 categories	74.71	12.87	5.52	5.75	1.15
	m = 0.5 g	0.3735	0.0644	0.0276	0.0287	0.0058
	m BA= 0.5 g	e 1 =11.4	e 2 =5.4	e 3 =20.01		
Sample 4	92% from initial separate 8 categories	70	11.2	4.8	5	1
	% of 5 categories	76.08	12.17	5.22	5.44	1.09

	m = 0.5 g	0.3804	0.0608	0.0261	0.0272	0.0055
	m BA= 0.5 g	e 1 =13	e 2 =6.84	e 3 =11.27		
Sample 5	97% from initial separate 8 categories	75	11.2	4.8	5	1
	% of 5 categories	77.32	11.55	4.95	5.15	1.03
	m = 0.5 g	0.3866	0.0577	0.0248	0.0257	0.0052
	m BA= 0.5 g	e 1 =	e 2 =7.44	e 3 =20.01		

Annex 5.

Table 1 contains all separation samples through study period.

Season	Month	Date	Waste type	Random Sample Kg	%		
Summer 2010	June	Sat.3		254			
			Organic and food wastes	164.9	64.92%		
			Plastics	31.6	12.44%		
			Paper and cardboard	11.8	4.65%		
			Glass	1.5	0.59%		
			Metals	2.6	1.02%		
			Textiles	15.3	6.02%		
			Wood	1.4	0.55%		
			Others	24.9	9.80%		
		Sun 2		243			
			Organic and food wastes	152.6	62.80%		
			Plastic	32.8	13.50%		
			Paper and cardboard	11.2	4.61%		
			Glass	0.8	0.33%		
			Metals	2.3	0.95%		
			Textiles	16.4	6.75%		
			Wood	1.2	0.49%		
			Others	25.7	10.58%		
				252.5			
		Wed 9	Organic and food wastes	161.4	63.92%		
			Plastics	32.8	12.99%		
			Paper and cardboard	12.8	5.07%		
Glass	1.6		0.63%				
Metals	2.6		1.03%				

			Textiles	12.3	4.87%	
			Wood	2.7	1.07%	
			Others	26.3	10.42%	
				263		
		Mon. 21	Organic and food wastes	161.7	61.48%	
			Plastics	32.3	12.28%	
			Paper and cardboard	13.1	4.98%	
			Glass	2.3	0.87%	
			Metals	3.7	1.41%	
			Textiles	19.3	7.34%	
			Wood	1.9	0.72%	
			Others	28.7	10.91%	
				252		
		Tue. 24	Organic and food wastes	160.7	63.77%	
			Plastics	29.4	11.67%	
			Paper and cardboard	9.8	3.89%	
			Glass	1.6	0.63%	
			Metals	2.8	1.11%	
			Textiles	19.3	7.66%	
			Wood	1.3	0.52%	
			Others	27.1	10.75%	
				277		
		Sat. 26	Organic and food wastes	183.6	66.28%	
			Plastics/rubber	34.8	12.56%	
			Paper and cardboard	12.6	4.55%	
			Glass	2.1	0.76%	
			Metals	2.8	1.01%	
			Textiles	16.2	5.85%	
			Wood	3.4	1.23%	
			Others	21.5	7.76%	

				247				
		Mon. 28	Organic and food wastes	148.1	59.96%			
			Plastics	34.1	13.81%			
			Paper and cardboard	9.7	3.93%			
			Glass	2.1	0.85%			
			Metals	4.4	1.78%			
			Textiles	17.2	6.96%			
			Wood	2.3	0.93%			
			Others	29.1	11.78%			
				277.1				
Summer 2010	July	Sat. 3	Organic and food wastes	171.8	62.00%			
			Plastics	32.6	11.76%			
			Paper and cardboard	6.8	2.45%			
			Glass	4.7	1.70%			
			Metals	6.2	2.24%			
			Textiles	13.6	4.91%			
			Wood	2.3	0.83%			
			Others	39.1	14.11%			
					262			
				Mon. 5	Organic and food wastes	168.6	64.35%	
					Plastics	34.8	13.28%	
					Paper and cardboard	8.4	3.21%	
					Glass	2.1	0.80%	
					Metals	3.2	1.22%	
					Textiles	16.3	6.22%	
					Wood	1.7	0.65%	
			Others		26.9	10.27%		
					254.3			
			Wed 7	Organic and food wastes	161.8	63.63%		
				Plastics	24.7	9.71%		

			Paper and cardboard	8.8	3.46%	
			Glass	2.4	0.94%	
			Metals	10.7	4.21%	
			Textiles	8.4	3.30%	
			Wood	3.4	1.34%	
			Others	34.1	13.41%	
				258.3		
		Thu. 8	Organic and food wastes	163.2	63.18%	
			Plastics	23.4	9.06%	
			Paper and cardboard	8.6	3.33%	
			Glass	2.6	1.01%	
			Metals	11.2	4.34%	
			Textiles	13.4	5.19%	
			Wood	2.4	0.93%	
			Others	31.5	12.20%	
				266.8		
		Sat. 10	Organic and food wastes	173.4	64.99%	
			Plastics	29.7	11.13%	
			Paper and cardboard	8.1	3.04%	
			Glass	2.5	0.94%	
			Metals	2.6	0.97%	
			Textiles	10.2	3.82%	
			Wood	2.6	0.97%	
			Others	38.4	14.39%	
				278		
		Tus.13	Organic and food wastes	171.8	61.80%	
			Plastics	31.4	11.29%	
			Paper and cardboard	6.8	2.45%	
			Glass	3.1	1.12%	
			Metals	6.2	2.23%	
			Textiles	13.6	4.89%	

		Wood	2.3	0.83%	
		Others	42.8	15.40%	
			256.3		
	Thu. 15	Organic and food wastes	164.2	64.07%	
		Plastics	25.4	9.91%	
		Paper and cardboard	9.7	3.78%	
		Glass	3.3	1.29%	
		Metals	14.8	5.77%	
		Textiles	11.4	4.45%	
		Wood	3.2	1.25%	
		Others	24.3	9.48%	
			277.3		
	Sat. 17	Organic and food wastes	166.9	60.19%	
		Plastics	27.7	9.99%	
		Paper and cardboard	12.1	4.36%	
		Glass	2.3	0.83%	
		Metals	5.4	1.95%	
		Textiles	16.3	5.88%	
		Wood	3.8	1.37%	
		Others	42.8	15.43%	
			252.5		
	Sun. 18	Organic and food wastes	157.9	62.53%	
		Plastics	28.7	11.37%	
		Paper and cardboard	9.6	3.80%	
		Glass	2.3	0.91%	
		Metals	4.3	1.70%	
		Textiles	11.5	4.55%	
		Wood	1.8	0.71%	
		Others	36.4	14.42%	
			264.3		
	Thu.	Organic and food	165.7	62.69%	

		22	wastes				
			Plastics	28	10.59%		
			Paper and cardboard	11.1	4.20%		
			Glass	2.9	1.10%		
			Metals	2.4	0.91%		
			Textiles	13.1	4.96%		
			Wood	2.6	0.98%		
			Others	38.5	14.57%		
				255			
		Sat. 24	Organic and food wastes		157.7	61.84%	
				Plastics	29.6	11.61%	
				Paper and cardboard	13.2	5.18%	
				Glass	2.7	1.06%	
				Metals	3.2	1.25%	
				Textiles	11.6	4.55%	
				Wood	2.1	0.82%	
				Others	34.9	13.69%	
				261.3			
		Sun. 25	Organic and food wastes		159.1	60.89%	
				Plastics	30.2	11.56%	
				Paper and cardboard	14.6	5.59%	
				Glass	2.5	0.96%	
				Metals	2.5	0.96%	
				Textiles	13.8	5.28%	
				Wood	2.7	1.03%	
				Others	35.9	13.74%	
				268.4			
		Wed. 28	Organic and food wastes		162.2	60.43%	
				Plastics	30.6	11.40%	
Paper and cardboard	13.8			5.14%			
Glass	2.3			0.86%			

			Metals	4.1	1.53%	
			Textiles	12.9	4.81%	
			Wood	2.4	0.89%	
			Others	40.1	14.94%	
				258.3		
		Thu. 29	Organic and food wastes	151.7	58.73%	
			Plastics	28.7	11.11%	
			Paper and cardboard	15.1	5.85%	
			Glass	2.8	1.08%	
			Metals	3.4	1.32%	
			Textiles	13.4	5.19%	
			Wood	2.6	1.01%	
			Others	40.6	15.72%	
				270.5		
	September	Sat. 25	Organic and food wastes	174.7	64.58%	
			Plastics	28.2	10.43%	
			Paper and cardboard	9.4	3.48%	
			Glass	2.8	1.04%	
			Metals	3.1	1.15%	
			Textiles	13.9	5.14%	
			Wood	1.8	0.67%	
			Others	36.6	13.53%	
				253.4		
		Sun. 26	Organic and food wastes	159.4	62.90%	
			Plastics	30.3	11.96%	
			Paper and cardboard	9.7	3.83%	
			Glass	2.3	0.91%	
			Metals	3.3	1.30%	
			Textiles	9.7	3.83%	
			Wood	0.9	0.36%	
			Others	37.8	14.92%	

				255.3				
		Tue. 27	Organic and food wastes	153.9	60.28%			
			Plastics	29.9	11.71%			
			Paper and cardboard	10.9	4.27%			
			Glass	1.7	0.67%			
			Metals	2.4	0.94%			
			Textiles	14.8	5.80%			
			Wood	1.9	0.74%			
			Others	39.8	15.59%			
				258.3				
		Thu. 30	Organic and food wastes	152.8	59.16%			
			Plastics	27.9	10.80%			
			Paper and cardboard	10.2	3.95%			
			Glass	1.5	0.58%			
			Metals	3.7	1.43%			
			Textiles	16.4	6.35%			
			Wood	3.4	1.32%			
			Others	42.4	16.42%			
				254.2				
Autumn	October 2010	Sun. 3	Organic and food wastes	171.4	67.43%			
			Plastics	22.6	8.89%			
			Paper and cardboard	11.1	4.37%			
			Glass	2.2	0.87%			
			Metals	5.2	2.05%			
			Textiles	4.6	1.81%			
			Wood	1.9	0.75%			
			Others	35.2	13.85%			
						260.3		
				Tue. 5	Organic and food wastes	168.2	64.62%	
		Plastics	19.8		7.61%			

			Paper and cardboard	19.7	7.57%	
			Glass	3.1	1.19%	
			Metals	4.7	1.81%	
			Textiles	9.6	3.69%	
			Wood	2.8	1.08%	
			Others	32.4	12.45%	
				253.8		
		Thu. 7	Organic and food wastes	164.7	64.89%	
			Plastics	18.4	7.25%	
			Paper and cardboard	14.6	5.75%	
			Glass	1.7	0.67%	
			Metals	1.8	0.71%	
			Textiles	10.3	4.06%	
			Wood	2.3	0.91%	
			Others	40	15.76%	
				264.3		
		Sun. 10	Organic and food wastes	165.2	62.50%	
			Plastics	23.9	9.04%	
			Paper and cardboard	13.8	5.22%	
			Glass	2.3	0.87%	
			Metals	3.1	1.17%	
			Textiles	12.6	4.77%	
			Wood	1.8	0.68%	
			Others	41.6	15.74%	
				259		
		Tue. 12	Organic and food wastes	163.9	63.28%	
			Plastics	28.7	11.08%	
			Paper and cardboard	14.8	5.71%	
			Glass	3.2	1.24%	
			Metals	2.4	0.93%	
			Textiles	14.6	5.64%	

		Wood	1.1	0.42%	
		Others	30.3	11.70%	
			257.2		
	Wed. 13	Organic and food wastes	163.9	63.72%	
		Plastics	28.9	11.24%	
		Paper and cardboard	14.8	5.75%	
		Glass	3.6	1.40%	
		Metals	2.4	0.93%	
		Textiles	10.7	4.16%	
		Wood	1.2	0.47%	
		Others	31.7	12.33%	
			254.8		
	Thu. 14	Organic and food wastes	161.6	63.42%	
		Plastics	26.8	10.52%	
		Paper and cardboard	12.3	4.83%	
		Glass	2.4	0.94%	
		Metals	2.5	0.98%	
		Textiles	13.7	5.38%	
		Wood	2.4	0.94%	
		Others	33.1	12.99%	
			259.3		
		Organic and food wastes	160.7	61.97%	
		Plastics	21.4	8.25%	
		Paper and cardboard	15.3	5.90%	
		Glass	1.9	0.73%	
		Metals	4.8	1.85%	
		Textiles	15.4	5.94%	
		Wood	3.7	1.43%	
	sat. 23	Others	36.1	13.92%	
			258.7		
	Tue.	Organic and food	157.9	61.04%	

		26	wastes			
			Plastics	25.6	9.90%	
			Paper and cardboard	12.4	4.79%	
			Glass	1.9	0.73%	
			Metals	6.7	2.59%	
			Textiles	12.9	4.99%	
			Wood	3.7	1.43%	
			Others	37.6	14.53%	
				254.4		
		Thu. 28	Organic and food wastes	147.2	57.86%	
			Plastics	27.6	10.85%	
			Paper and cardboard	18.8	7.39%	
			Glass	3.6	1.42%	
			Metals	3.2	1.26%	
			Textiles	14.4	5.66%	
			Wood	5.2	2.04%	
			Others	34.4	13.52%	
				252.8		
		Sun. 31	Organic and food wastes	150.8	59.65%	
			Plastics	27.1	10.72%	
			Paper and cardboard	14.8	5.85%	
			Glass	3.9	1.54%	
			Metals	7.8	3.09%	
			Textiles	7.3	2.89%	
			Wood	2.5	0.99%	
			Others	38.6	15.27%	
				267.6		
Autumn	November	Tue. 2	Organic and food wastes	166.4	62.18%	
			Plastics/rubber	28.9	10.80%	
			Paper and cardboard	13.8	5.16%	
			Glass	2.6	0.97%	

			Metals	4.2	1.57%	
			Textiles	14.3	5.34%	
			Wood	2.3	0.86%	
			Others	35.1	13.12%	
				267.9		
		Wed.3	Organic and food wastes	166.4	62.11%	
			Plastics	28.9	10.79%	
			Paper and cardboard	14.6	5.45%	
			Glass	3.1	1.16%	
			Metals	4.7	1.75%	
			Textiles	9.8	3.66%	
			Wood	3.3	1.23%	
			Others	37.1	13.85%	
				258.9		
		Sun. 7	Organic and food wastes	172.2	66.51%	
			Plastics	27.1	10.47%	
			Paper and cardboard	11.6	4.48%	
			Glass	1.6	0.62%	
			Metals	2.4	0.93%	
			Textiles	9.6	3.71%	
			Wood	2.1	0.81%	
			Others	32.3	12.48%	
				260.2		
		Tue. 23	Organic and food wastes	162.8	62.57%	
			Plastics	26.4	10.15%	
			Paper and cardboard	13.7	5.27%	
			Glass	2.1	0.81%	
			Metals	3.3	1.27%	
			Textiles	12.7	4.88%	
			Wood	1.9	0.73%	
			Others	37.3	14.34%	

				257.3		
		Thu. 25	Organic and food wastes	162.9	63.31%	
			Plastics	26.4	10.26%	
			Paper and cardboard	13.8	5.36%	
			Glass	2.2	0.86%	
			Metals	3.5	1.36%	
			Textiles	9.8	3.81%	
			Wood	1.9	0.74%	
			Others	36.8	14.30%	
				251.8		
		Sat. 27	Organic and food wastes	150.3	59.69%	
			Plastics	28.1	11.16%	
			Paper and cardboard	13.2	5.24%	
			Glass	2.9	1.15%	
			Metals	3.7	1.47%	
			Textiles	10.8	4.29%	
			Wood	3.5	1.39%	
			Others	39.3	15.61%	
				254.9		
		Mon. 29	Organic and food wastes	152.7	59.91%	
			Plastics	27.9	10.95%	
			Paper and cardboard	12.7	4.98%	
			Glass	2.8	1.10%	
			Metals	2.9	1.14%	
			Textiles	13.9	5.45%	
			Wood	2.5	0.98%	
			Others	39.5	15.50%	

Table 2 of Average rates separation of waste stream

Waste Types	Month					Average (%)	St. Dev.
	June	July	September	October	November		
	%						
Food Waste	63.30	62.30	61.90	62.76	62.33	62.52	0.5341
Plastics	12.75	11.01	11.25	9.58	10.65	11.05	1.1466
Paper & cardboard	4.52	3.92	3.88	5.74	5.13	4.64	0.8012
Textile	6.49	4.90	5.21	4.45	4.45	5.10	0.8423
Wood	0.79	1.00	0.73	1.01	0.96	0.90	0.13001
Glass	0.67	1.05	0.81	0.96	0.95	0.89	0.15016
Metals	1.19	2.21	1.19	1.49	1.36	1.49	0.42497
Others	10.29	13.60	15.03	13.82	14.17	13.38	1.81288

Annex 6.

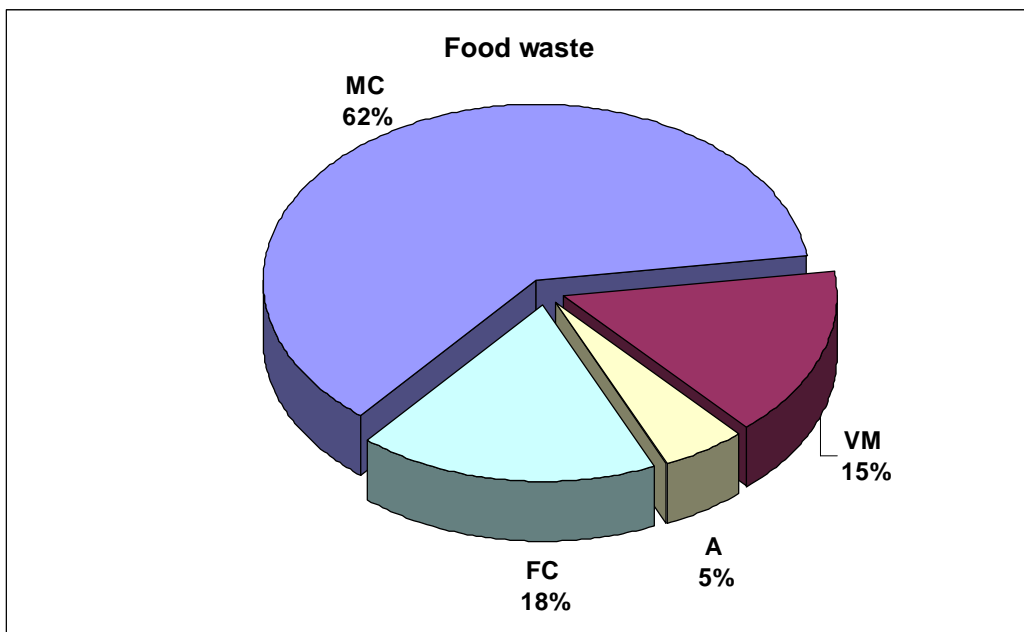


Fig. 1: Shows rates the MC, A, VM and FC for Food waste

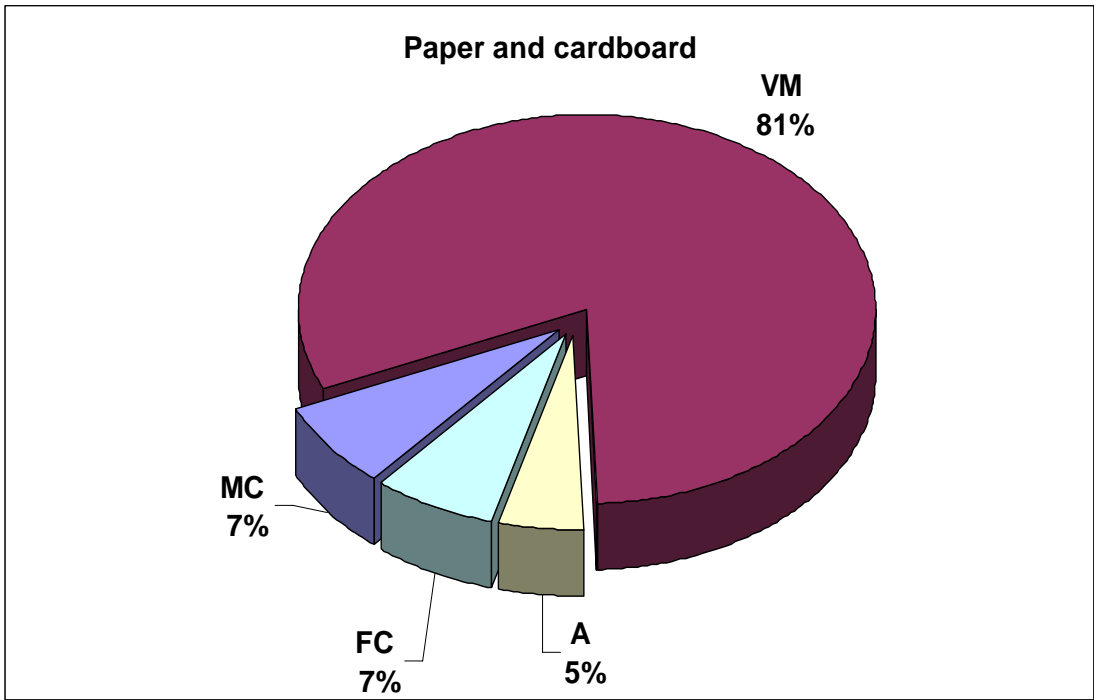


Fig. 2: Shows rates the MC, A, VM and FC for Paper and cardboard

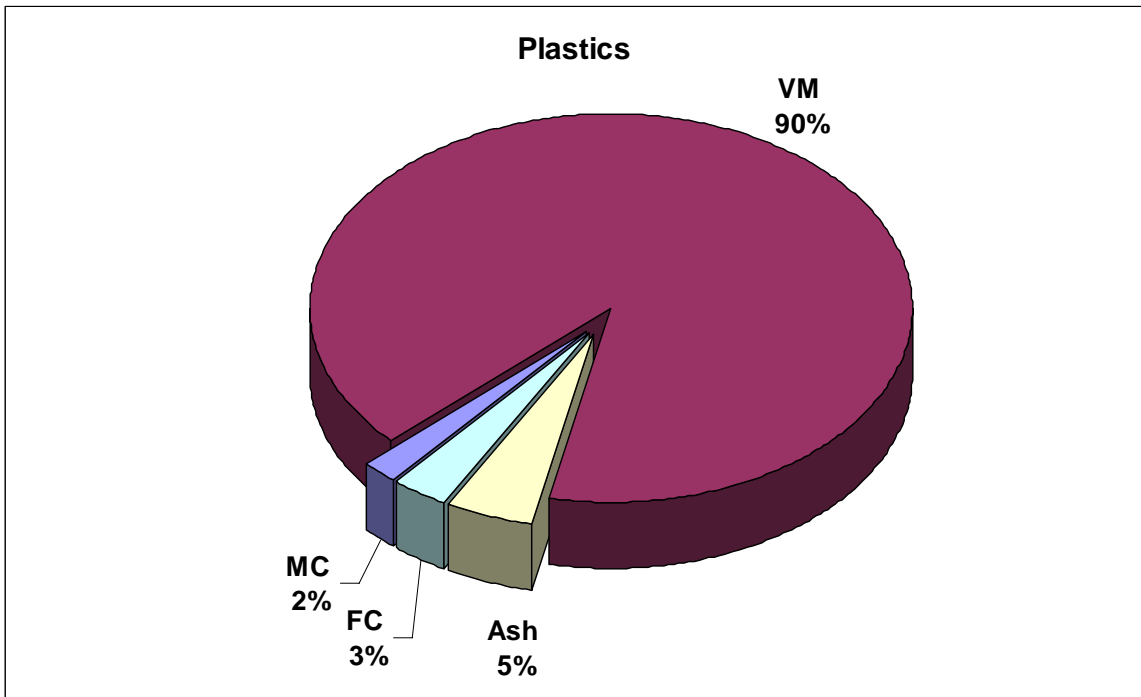


Fig. 3: Shows rates the MC, A, VM and FC for Plastics.

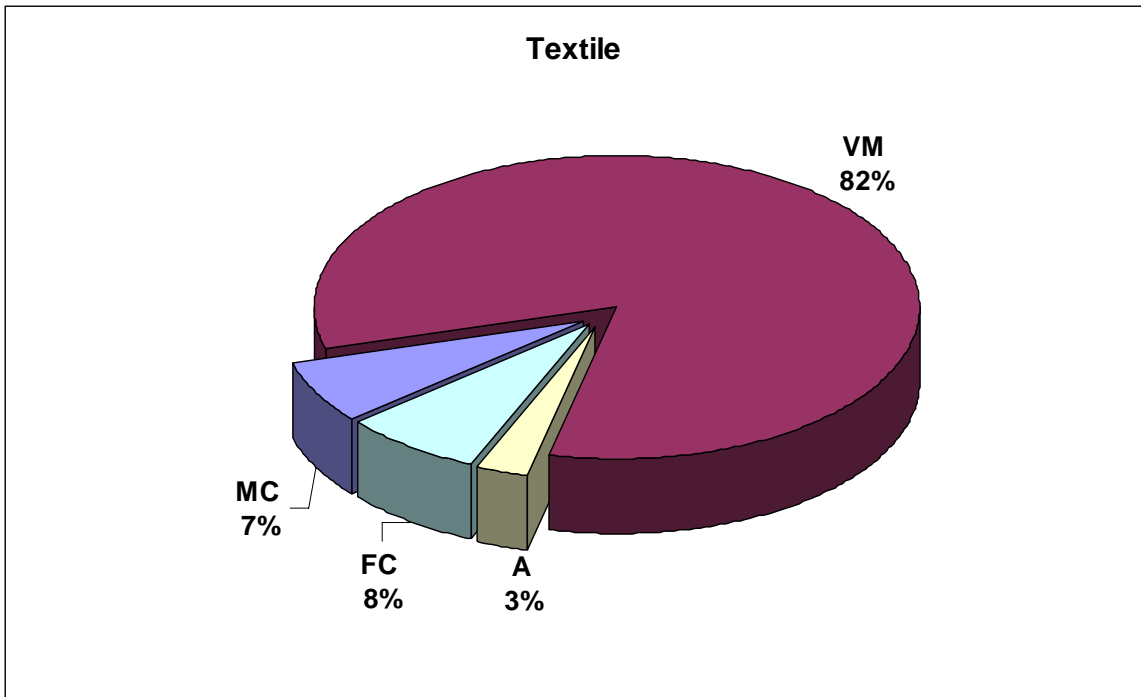


Fig. 4: Shows rates the MC, A, VM and FC for Textile

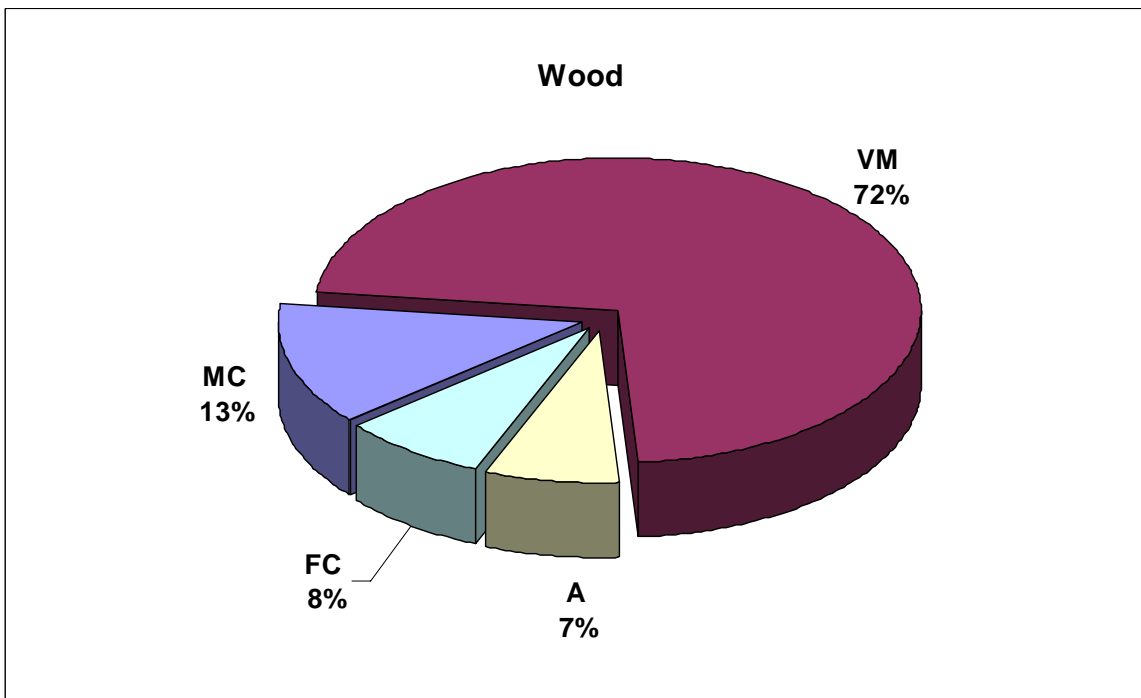


Fig. 5: Shows rates the MC, A, VM and FC for Wood

Annex 7

Table 1: Calorific values for dry samples

Waste Type	Calorific Value (Dry) MJ/kg	Average Calorific Value MJ/kg
Food Waste 1	15.83692	16.09
Food Waste 2	16.31247	
Food Waste 3	16.15093	
Paper and Cardboard 1	17.34065	16.97
Paper and Cardboard 2	16.92681	
Paper and Cardboard 3	16.65372	
Plastic 1	40.20840	39.4
Plastic 2	37.30390	
Plastic 3	40.79070	
Textile 1	14.83278	14.55
Textile 2	14.32014	
Textile 3	14.50804	
Wood 1	17.19552	18
Wood 2	18.59117	
Wood 3	18.24089	