EVALUATION OF ENERGY POTANTIAL OF MUNICIPAL SOLID WASTE FOR DIRECT WASTE COMBUSTION IN ISTANBUL

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ABSTRACT

In this study, municipal solid wastes (MSW) produced in Esenler Municipality of İstanbul Metropolitan City has been characterized, considering three different income groups by selected areas with low, moderate and high income. The MSW were classified as 16 groups and their percentages in weight were obtained. MSW sampling campaign were carried out summer and winter seasons during 2017. A detailed MSW classification showed that MSW character varied reasonably among these income groups pointing out that biodegradable material rate was higher at low income whereas paper and carton wastes were higher at high income area. In the light of MSW characterization by income groups, i) bomb calorimetry analysis is used to determine thermal energy of MSW, and ii) to understand thermal properties of different MSW samples such as exothermic or endothermic conditions within waste combustion with increased temperature, Thermogravimetric Analysis (TGA) & Differential Scanning Calorimetry (DSC) have been conducted and evaluated.

1. INTRODUCTION

Municipal solid wastes (MSWs) including domestic wastes and water treatment sludge are heterogeneous wastes characterized by the waste type and local attributes they were produces. The amount of solid waste produced in a region is not only a function of the living standard, but also the lifestyle and socioeconomic status of the residents living there. Management of MSWs has emerged as one of the biggest challenges faced by environmental protection agencies in developing countries [1-3]. As the world turns to the urban areas, solid waste management in these areas becomes more important than before. Ten years ago, while 2.9 billion people were living in cities, we were seeing an increase of about 0.64 kg per capita per day, which is the reason for this increase. The number of people producing waste was 3 billion and the average amount of waste produced per capita will predicted to be 1.2 kg up to 2025, which shows rates tend to increase by years. An estimated count of 4.3 billion residents will produce 1.42 kg per capita-day waste in near future. Therefore, regulatory arrangements should be made in order not to grow in this regard [4-5].

Waste-to-Energy processes can be used as a treatment method for wide range of wastes, considering energy recover and economic benefits. Particularly, the purpose of waste incineration is to treat (and intensify) or destroy the potentially harmful substances while reducing the volume and damage of the waste by treating the waste as in most of the waste treatment processes. Moreover, the incineration process can provide a method for recovering energy, mineral and/or chemical content from the waste. Municipal waste incineration in Europe as solid waste disposal method is used for over 50 years. The main benefit of preferred thermal methods is the mass and volume reduction of wastes by incineration in some countries where landfilling opportunities for landfills are limited [1, 3-4]. Nearly 400 solid waste incineration plants in the European Union countries are disposing 59 million tons of domestic solid waste per year. In the United States, there are 87 waste incineration plants where household wastes are disposed by incineration. Instead of storing and disposing of solid wastes in the framework of EU harmonization process, it is necessary for Turkey to find new solutions in order to minimize the damages to the environment and to give an economic sense to waste disposal [1, 3, 6-8].

In this study, MSWs produced in Esenler Municipality of Istanbul Metropolitan City has been characterized considering three different income groups considering the areas with low-income, mid-income and high income. The collected MSW were classified as 16 groups and their percentages were obtained. MSW sampling were carried out summer and winter seasons during 2017. A detailed MSW classification showed that MSW character varied reasonably among these income groups pointing out that biodegradable material rate was higher at low income whereas paper and carton wastes were higher at high income area. In the light of MSW characterization by income groups, i) bomb calorimetry analysis is used to determine thermal energy of MSW, and ii) to understand thermal properties of different MSW samples such as exothermic or endothermic conditions within waste combustion with increased temperature, Elementel Analysis, Thermogravimetric Analysis (TGA) & Differential Scanning Calorimetry (DSC) have been conducted [9-10]. Bomb calorimetry analysis is used to efficiently measure the heat released during combustion reactions of MSW, which gives higher and lower heating (HHV and LHV in kcal/kg) values of MSW as well as water and organic matter contents (%) of MSW.

2. MATERIAL AND METHODS

2.1. MSW sampling

Esenler Municipality of Istanbul Metropolitan City was researched for MSW characterization and thermal properties. It is the 11th smallest district of Istanbul in terms of surface area. As of 2016, the population of Esenler is 457.231. In this study, the Solid Waste Characterization Method was used as the standard method for the determination of the compositions of untreated urban wastes, which was established in many internationally recognized and accepted American standard technical methods [11-12].

2.2. MSW characterization study

In the district where the solid waste characterization is to be carried out during summer and winter periods in 2017, samples are taken on Monday and Tuesday with separate waste collection vehicles from three different regions in Esenler district, including low-income (Nene Hatun vicinity), mid-income (downtown) and high income (Mimar Sinan vicinity) areas. The reason for bringing the wastes generated on Mondays and Tuesdays is that collecting samples representing both the weekend and the weekdays. The quantities of these wastes to be made for characterization should be the same as the quantities received and should be taken under expert supervision [13-15]. It is appropriate that the area where the waste separation is to be made has a smooth slope and was covered with a durable plastic at least 5x10 m dimensions laid on during the process. The weighbridge is calibrated before weighing. Waste collection vehicles from different regions pour out of the wastes so that each will form a separate batch. The discharged stacks are flattened separately. The waste shall be placed in equal amounts in each part of the pile, so that it will completely fill the inside of the fixed volume vessel (1x1x1 m or 0.5x0.5x0.5 m) from any of the stacks to be sampled. To be distinguished, the labels of the groups of substances (plastic, metal, glass, etc.) are affixed on the containers to avoid confusion. Sixteen components were identified in solid waste characterization with a separate container for each component in the separation process. These waste components are classified in Table 1.

The empty weights (tare) of the containers record before proceeding to item group analysis during the characterization study. Then all the wastes were put into the appropriate ones from this pile spread on the plastic cover so as to leave food residues to the end. Mass loss may occur during grouping due to water evaporation. So the collected wastes should be separated as quickly as possible [11]. The full container mass is weighed and noted. In winter, wastes should be passed through a screen having a diameter of 1 cm. The rest on the top is placed in the same container and weighed, weighing is noted. The difference between weighing made before and after the sifting of the wolf gives the weight of the pheasant. The amount of ash is thus separately found for each component. After all the groups have finished weighing, these weights are collected and the amount of ash in the total sample is obtained.

Table 1. Solid waste characterization categories.

Type	Sources
Organic	Food scraps, yard (leaves, grass) waste, wood, process residues
Paper	Paper scraps, cardboard, newspapers, magazines, bags, boxes
Carton	Milk cans, fruit juices cans, etc.
Volumed Carton	Carton boxes, etc.
Plastic	All plastic materials
Glass	Glass bottles, cups, etc.
Metal	Metal boxes, forks, knives, etc.
Volumed Metal	Metal cages, desks, etc.
Waste electric and electronic equipment	Telephone, radio, etc.
Hazardous waste	Battery, paint bins, detergent bins, drug bins, etc.
Park and garden waste	Branches, tree limbs, grass, etc.
Other incombustibles	Stones, sand, ceramic, etc.
Other combustibles	Textile wastes, napkins, shoes, slippers, pillows, carpets, bags, etc.
Other volumed incombustibles	Undefined volumed incombustibles
Other volumed combustibles	Furniture and wooden materials, etc.
Others	Unclassified materials

2.3. Thermal and Elementel Analysis

Before thermal analysis, all the samples were dried at 105 °C for 48 h in an oven and then ground, blended and finally sieved through a 0.2 mm pore diameter sieve. Thermogravimetric (TGA) and differential scanning calorimetry analysis (DSC) have been applied to the dried samples to determinate the mass loss and heat flow profiles as a function of temperature under a controlled atmosphere. This type of analysis is widely used to characterize the phenomena of evaporation, thermal decomposition and combustion properties. In this work, TGA were carried out on a Shimadzu DTG 60H (TA-60WS) with a heating rate of 20 °C/min until 1200 °C, burning 5 mg sample of the waste under a flow of 20 ml/min high-purity nitrogen. DSC were carried out on Shimadzu DSC 60 (TA-60WS) with a heating rate of 10 °C/min until 1200 °C, burning 5 mg sample of the waste under 20 ml/min nitrogen flow. Bomb calorimetry of a sample size of 0.5–1.0 g on PARR 6100 Calorimeter is used to determine experimental heating value of combustion.

Element analyses for determining percentages of C, H, N, O and S in the samples were performed on a Thermo-Scientific Flash 2000 elementel analyzer. The elementary composition was determined through quantitative high temperature decomposition. For such determination, the samples are converted into gaseous compounds under controlled atmosphere. By using thermal analysis methods proximate (moisture, volatile combustible matter, fixed carbon and ash) and ultimate (percentages of C, H, O, N and S) properties of the samples were obtained.

3. RESULTS AND DISCUSSION

3.1. Basic MSW characterization results

In order to sample MSWs considering high, moderate and income levels by location, a sampling campaign have been conducted. So, three different region with low-income (Nene Hatun vicinity), mid-income (downtown) and high income (Mimar Sinan vicinity) in Esenler district with a population of 5000 were determined by interviewing. Generally, about 1-ton (~3-4 containers) waste samples from each income group were collected by cleaning and separating the MSW for analysis. Wastes were shredded while separating the easily separable groups (paper, cardboard, metal, glass, etc.) into categories and an attention has been paid to remove it from residues. Residual ash mixed wastes were passed through the sieve with a pore size of 1 cm^2, and the waste from the sieve was re-separated while the waste from the sieve was evaluated as ash and the amount of ash was determined. The measurements were made over a volume of 0.5 m^3, so the results were doubled.

Winter period solid waste characterization studies started in February, 2017 and finalized in March, 2017. Due to the unfavorable weather conditions, the MSW were usually collected weekly, which led to a longer period of work. Summer season work started in June, 2017 and ended in July, 2017. Waste statistics for wastes collected from high and low-income areas in Esenler are summarized in Table 2 for 17 waste categories, showing the average waste composition according to wet weight of MSW obtained from weekdays and weekend sampling statistics. It was seen that especially the amounts of waste organic wastes (Mimar Sinan-35.51% and Nene Hatun- 43.64%), textile wastes (22.98% and 15.77%) and paper-cardboard (10.96% and 5.90%) were more than the amount of the other category members.

Table 2. The average MSW statistics with high and low-income areas.

Group	Material	High Income (%)	Low Income (%)	Weekdays (%)	Weekend (%)	Average (%)
1	Paper-Carton	10.526	6.902	8.428	9	8.714
2	Glass	2.623	2.308	2.049	2.881	2.465
3	Pet	1.121	0.47	0.703	0.888	0.795
4	Bag	9.1	11.079	9.339	10.84	10.09
5	Plastic	2.218	1.469	1.816	1.871	1.844
6	Metal	0.308	0.503	0.328	0.483	0.405
9	Organic wastes	42.69	47.853	39.574	50.969	45.271
10	Waste electric and electronic equipment	0.349	0.12	0.366	0.104	0.235
11	Hazardous waste	0.489	0.293	0.307	0.475	0.391
12	Tetrapak	0.49	0.438	0.338	0.589	0.464
13	Textile	14.458	12.644	19.375	7.727	13.551
14	Diaper	5.946	8.006	7.364	6.588	6.976
15	Park and garden wastes	0.247	0.127	0.127	0.247	0.187
16	Other combustibles	8.784	7.253	8.847	7.19	8.018
17	Other incombustibles	0.644	0.529	1.032	0.14	0.586
	TOTAL	***100***	***100***	***100***	***100***	***100***

Fig. 1 shows a detailed pie-chart of the percentages of MSW categories for weekdays and weekend, respectively. On weekdays and weekends, the most obvious difference in waste character appears to be textile wastes. The reason for this large difference of 17% in the area was the textile firms closed on the weekend as the biggest source of textile wastes.

Also, there is an increase in organic wastes at the weekend. So, people are more likely to go to the fast-food on the weekend, causing the increase of the organic waste. In addition to these fast foods, the intake of soft drinks generally makes a differentiable ratio in glass amount. The increase in the number of bags, people market, bazaar-market and clothing can usually be considered as increasing shopping habits at weekends. As can be seen from these tables, the characterizations of the wastes in the cities vary depending on the different parameters. Changes in the weekday and weekend waste groups provide us reliable data about of the district character. As shown in Table 2 and Fig. 1, there are also various differences between the high-income group and the low-income group. The paper and cardboard waste group is higher than the low-income group.

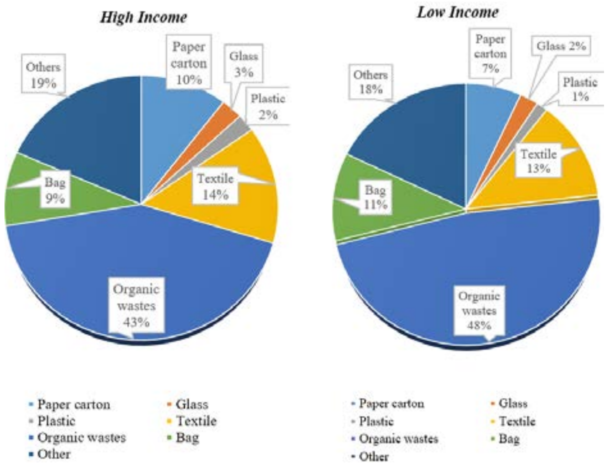

Fig. 1. MSW characterization chart by income level.

3.2. Proximate and ultimate analysis results

The thermal conversion of municipal solid waste in a Waste-to-Energy plant calls for detailed understanding of the process. The process depends on several input parameters like proximate and ultimate analyses of the waste feed. Ultimate analysis uses the chemical makeup of the fuel to approximate its heat value. Fig. 2 shows the averaged elementel analysis results (C, O, N, H and S) with line plots for the income-level based wastes on dry based. Dry based elementel compositions for all waste groups were similar according to the percentages of C:

70.83, 72.14, 69.45, O: 20.19, 19.82, 20.92, N: 0.547, 0.12, 0.15, H: 8.29, 7.75, 9.31 and S: 0.14, 0.17, 0.18, for low moderate and high-income levels, respectively. Based on these values an approximate heating value as higher heating value (HHV) was found to be in the range of 5400-8800 kcal/kg [16].

Table 3 shows the proximate analysis results for income-level based waste groups. Here, moisture content (%) was ranged in 42-49 with a mean of 45.8%, HHV (kcal/kg) was between 3390-4129 with a mean of 3498 kcal/kg, LHV (kcal/kg) was between 1605-2161 with a mean of 1711 kcal/kg and organic content (%) was between 82-86 with a mean of 81% (wt). According to proximate analysis results, it could be seen that MSWs produced within Esenler vicinity have mostly organic character with high moisture content. Also, this is a common issue for the wastes produced in Turkey due to mixed collection of kitchen and other organic wastes with high moisture content together, which also shows the MSWs were not separated at source.

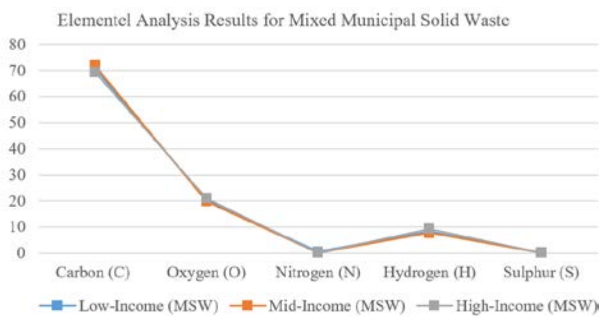

Fig. 2. Averaged elementel analysis results for income group based waste categories.

Table 3. Proximate analysis statistics for moderate, high and low-income waste groups.

Income Group	Moisture content, %		HHV, kcal/kg		LHV, kcal/kg		Organic matter, %	
	Avg.	Std. dev	Avg.	Std.dev	Avg.	Std. dev	Avg.	Std. dev
Overall	*45.8*	*6.0*	*3498.0*	*262.8*	*1711.1*	*401.6*	*81.1*	*0.2*
Moderate	46.7	2.9	4129.0	502.1	2161.9	291.7	85.9	1.6
High	48.8	3.1	4069.8	438.4	2041.9	181.0	82.9	1.7
Low	42.4	6.1	3390.3	202.1	1605.4	367.3	82.0	0.8

3.2. TGA/DSC analysis results

TGA is a reliable and widely used laboratory technique employed to study the extent of mass changes due to volatilization and combustion of fuel components. Fig. 3 shows the TGA curves obtained MSWs for low, moderate and high-income groups. The tested MSW samples degraded from 88% (low-income) to 95% wt. (mid-income) on dry basis as shown in Fig. 3. TGA curves shows that the burning temperature of the mixed MSW is about 500 ^{0}C. Thus, a weight loss of 65-70% of MSW samples has occurred at about 500 ^{0}C. The residues for MSW samples from low, moderate and high-income groups were 12%, 5% and 8%, respectively. Here, TGA curves showed a first phase weight loss of 6% for low and moderate-income groups whereas weight loss in this phase for high income group was about 15%. This indicated moisture content and highly volatile components were higher than those of the wastes from high income group. The next weight loss of about 50% for all waste group was similar for all income groups. The char available in the residues were lower at mid-income group waste. However, considering waste combustion process, MSW with high ash content hinder the combustion of char due to the layer of ash that is formed on the surface and which inhibits the diffusion of oxygen into the char [17].

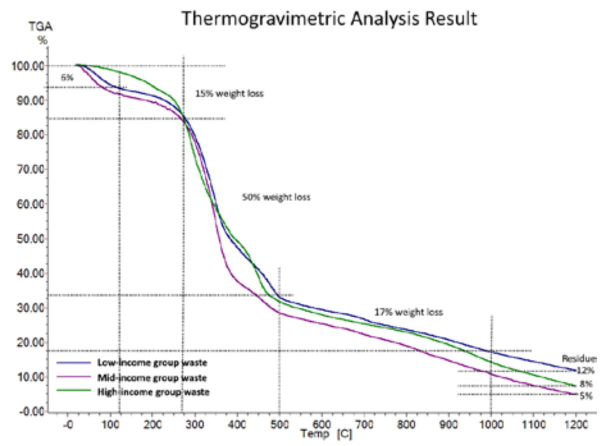

Fig. 3. TGA curves for income group based waste categories.

Fig. 4 shows the DSC combustion curves for each MSW group, which represents weight heat flux (exothermic peaks upside down) as functions of temperature. Here, many exothermic peaks were occurred, but, the significant peaks were at 95-100 ^{0}C due to oxidation of lower carbon components, 250 ^{0}C, 350 ^{0}C and 400 ^{0}C showing oxidation stages of lignocellulosic materials. However, just a few endothermic peaks were occurred at about 150 ^{0}C, 300 ^{0}C (low and mid-income group wastes) and 425 ^{0}C (low and high-income group wastes), in which black carbon continued to absorb heat, and the absorption rate increased at above 150 °C.

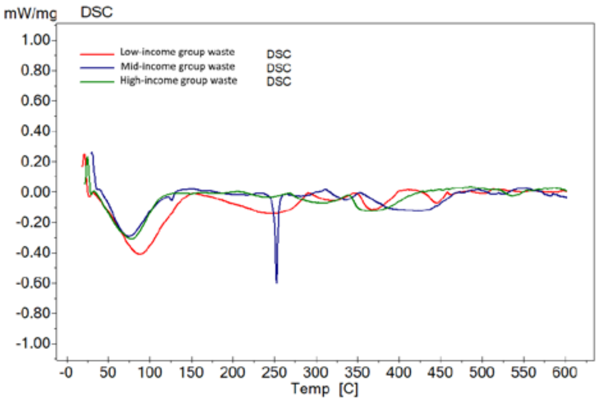

Fig. 4. DSC heat profiles for waste categories.

DSC profiles correspond to the decomposition stages observed in the TGA curves. Based on these results we can say that mid-income group wastes exhibit a different combustion behavior. The nature of the 250 ^{0}C peaks could be attributed to oxidation of the carbonyl and carboxyl containing volatiles molecules released from plastics. So, it can be concluded that moderate-income group wastes included more plastic and PVC materials.

According to results, average water content and organic matter fractions were 45.8% and 81.1%, and HHV and LHV values were 3498 and 1711 kcal/g, respectively. The waste is theoretically feasible for combustion without auxiliary fuel via direct combustion when: water fraction < 50%, ash content < 60% and combustible fraction > 25% (Skoog et al., 1998; ASTM, 2003). Also, Tanner Diagram may give a key point related to burning of waste. Considering minimum HHV and LHV values of 3390 and 1605 kcal/kg, at least 40% combustible material fraction and a water content < 50%, MSW produced in Esenler Municipality is feasible to be direct combusted.

4. CONCLUSIONS

The general situation of waste incineration technology which is widely used as municipal solid waste disposal method especially in developed countries and its applicability to Istanbul is evaluated. MSWs from low, moderate and high-income regions were characterized. Solid waste characterization in the environment and sustainable development process; efficient and speedy implementation of municipal services on waste management has great importance in monitoring environmental policies. The solid waste characterization study and the Esenler Municipality solid waste components were determined and an evaluation was made in terms of the compatibility of the waste with the burning ability by calorific value analysis. According to MSW characterization and of bomb calorimetry results, Esenler MSW is feasible to be direct combusted. However, in order to assess energy potential of MSW produced in Istanbul Metropolitan City overall, further researches on MSW characterization and calorific value determination are needed.

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