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Municipal Solid Waste Management Evaluation

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ABSTRACT

Imagine a waste-less world seems to be impossible but, we can make it happen throughout having the circular economy where we use resources repeatedly and recycle materials endlessly. Solid waste management became more challenging during the last decades because the 3-R (reduce-reuse-recycle) traditional management method does not fulfil the needs anymore and new strategies are shifting toward energy recovery approaches. While the percentage of solid waste constitutions and the moisture content differ between regions hence, the heat value produced from them varies from one country to another. In this study two sets of municipal solid waste (MSW) from Tehran city have been investigated in comparison with one sample of US MSW, and their heat values had been calculated based on modified Dulong equation considering different constitutions and further splitting them into molecules and atoms which they are consist of. Municipal solid waste includes organic, inorganic, combustible, and recyclable materials. Results showed the higher the moisture content the lower the heat value.

Keywords: Municipal solid waste, Combustible component, Heat value, Modified Dulong Equation.

Introduction

Practical design for Waste Management focused mainly on more sustainable and environmentally friendly Solutions at the recent years. Today's attention has shifted toward efficient use of natural resources turns up to waste reduction [1]. Resource efficiency implies minimization of material losses and maximization the material circulation [2]. Recognition of waste as a potentioal source of energy is key element of solid waste management [3-5]. In this study three sets of municipal solid waste have been analyzed and separated further to their constitution elemetns and their released heat heat values have been calculated based on modified Dulongs equation. By combustion of solid waste released heat is partially stored in the combustible products (gasses and ash) and partly transferred by convection. The energy content of the waste can be estimated by using the modified Dulang equation presented in Eq.1[6-8].

$$E = 337 * C + 1428\left(H - \frac{O}{8}\right) + 9 * S. \quad (1)$$

In 2008 Yooen et al studied increasing industerial and municipal solid waste due to South Korea industerial and economic growth [9]. Waste to energy techniques are effective for waste management since more than 80 percent of renewable energy comes from waste energy mainly from combustible ones [10]. Most recent researchs are focoused on thermoelectrical power generation which have been directed towards utilization of industerial waste heat [11]. Recently,

the possibility of utilizing the heat from incinerated municipal solid waste has also been considered [12]. For instance , in Japan the solid waste per capita is around 1 kg per day [13] can Life cycle assesment (LCA) can be applied to MSW results as it has been used for anaerobic treatment process [14]. Having efficient system of Municipal Solid Waste management needs appropriate constitution assessment of solid waste. MSW has a specific physical chemical and biological characteristics. For instance, some physical characteristics of MSW are specific weight, moisture content, particle size and distribution. Specific weight or density of MSW determined as weight of solid waste divided by unit of volume, which is shown by kg /m^3, lb./ft^3, lb./yd^3. Solid waste density is much lower at indoor collection level from houses due to low compaction in comparison to collection level at containers either fixed or movable as well as landfill sites.

Iran municipal solid waste

Municipal solid waste base density considered to be 450 kg /m^3 in Iran. This value is reduced to one third at the houses collection level (Figure 1). shows a trash cells and silos at in Tehran , Kahrizak as well as a new incinerator in Copenhagen, Denmark which holds more than 24000 tons of waste materials. Automatic cranes mix the waste to help it burn cleaner.

Energy life cycle for solid waste which includes raw materials to waste production phase presented in (Figure 2) [15,16].

Materials and Methods

Available data

Municipal Solid Waste (MSW) constituents, and moisture content are essential components of waste chemical formula and helps us to derivate heat value of MSW from its formula (Table 1). below shows sample analysis of the combustible components for residential MSW based on integrated Solid Waste Management engineering principles and management issues. (See S.I.1) Based on (Table 2). Percentage of

Figure 1: Solid Waste Management (a) Kahrizak Landfill Cells, Tehran, (b) Tehran municipality waste management, (c)Trash silo at a new incinerator in Copenhagen, Denmark. (Fig. 1. (c) Courtesy to National Geography Magazine March 2020).

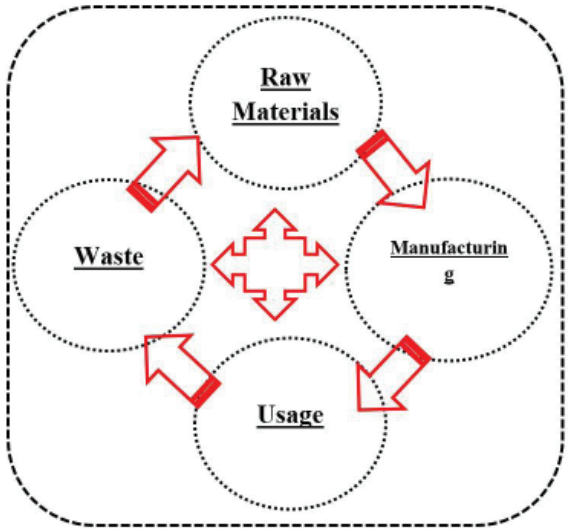

Figure 2: Energy life cycle through different phases. (a) Raw material, (b) Manufacturing, (c) Usage, (d) waste management.

Table 1: Typical data on the ultimate analysis of the combustible component in residential MSW (Courtesy to Integrated solid waste management: Engineering principles and management issues.) [17].

	Percent by weight, kg					
Organic Components	Carbon	Hydrogen	Oxygen	Nitrogen	Sulfur	Ash
Food Waste	48	6.4	37.6	2.6	0.4	5
Paper	43.5	6	44	0.3	0.2	6
Cardboard	44	5.9	44.6	0.3	0.2	5
Rubber	78	10	----	2	----	10
Plastics	60	7.2	22.8	----	----	10
Textile	55	6.6	31.2	4.6	0.15	2.5
Yard Waste	47.8	6	38	3.4	0.3	4.5
Textile	49.5	6	42.7	0.2	1	1.5

Table 2: Two sets of MSW data in residential area of Tehran.

Organic Components	Wet weight, (kg) First set of data	% of Moisture	Dry Weight (kg)	Wet weight, (kg) Second set of data	% of Moisture	Dry Weight (kg)
Food Waste	59.6	70	17.88	68.1	70	20.43
Paper	5.23	6	4.92	4.03	6	3.79
Cardboard	5.27	5	5	4.85	5	4.61
Rubber	2.6	2	2.55	1.06	2	1.568
Plastics	6.45	2	6.32	5.35	2	5.24
Textile	4.16	10	3.74	4.1	10	3.69

each single elements has been calculated for all MSW component in a dry basis. For instance, Dry weight of food waste is equal to 17.88

kg and carbon consists 48 percent of dry weight hence: 0.48*17.88 = 8.58 kg. The same procedure has been applied to all component to calculate the element percentage of the weight of solid waste components (Table 3, 4) and 5 below showed the percentage weight of elements for both sets of Tehran MSW components as well as USA sample. By subtracting first two columns of (Table 3, 5) moisture content has been calculated for all three samples. (See S.I.2) (Table 6) through 8 present the moisture content and its additive effect in the amount of hydrogen and oxygen elements. Added amount of oxygen and hydrogen is clear in first and second row of (Table 6-8) respectively. (See S.I.3) Percentage weight defined as weight of each single element divided by total weight. (See S.I.4) Atomic weight based on periodic tables has been used in calculating number of molls of each element. (See S.I.4)

Chemical formula derivate with and without sulfur

Without sulfur: In this part, chemical formula of MSW has been calculated by considering zero for sulfur and value of one for nitrogen component and calculating others based on new proportion of nitrogen. (See S.I.5) Hence the chemical formula is derived out from row two of (Table 9). below.

With sulfur: Chemical formula of MSW has been calculated by considering one for sulfur and calculating others based on new proportion of sulfur. (See S.I.6) Hence the chemical formula is derived out from row three of (Table 9). above. Applying the same procedure for the rest of data gives us chemical formula with and without sulfur and presented in (Table 10, 11), respectively.

Results

Chemical formula

Chemical formula with and without sulfur has been calculated and presented below as discussed in detail in previous section (Figure 4). presents the graphical format of MSW elements through both

Table 3: Organic components of MSW, Tehran Sample data 1.

Percent by weight, Data Set 1, (kg)

Organic Components	Wet weight (kg)	Dry weight(kg)	Carbon (C)	Hydrogen (H)	Oxygen (O)	Nitrogen (N)	Sulfur (S)
Food Waste	59.6	17.88	8.58	1.14	6.72	0.46	0.07
Paper	5.23	4.92	2.14	0.3	2.16	0.014	0.01
Cardboard	5.27	5	2.3	0.3	2.23	0.015	0.01
Rubber	2.6	2.55	1.99	0.23	------	0.05	----
Plastics	6.45	6.32	3.8	0.46	2.07	----	----
Textile	4.16	3.74	2.1	0.25	1.17	0.17	0.01
Sum	83.31	40.41	20.91	2.68	14.35	0.709	0.1

Table 4: Organic components of MSW, Tehran Sample data 2.

Percent by weight, Data set 2, (kg)

Organic Components	Wet weight (kg)	Dry weight(kg)	Carbon (C)	Hydrogen (H)	Oxygen (O)	Nitrogen (N)	Sulfur (S)
Food Waste	68.1	20.43	9.81	1.31	7.68	0.53	0.08
Paper	4.03	3.79	1.65	0.23	1.67	0.011	0.008
Cardboard	4.85	4.61	2.03	0.27	2.05	0.014	0.009
Rubber	1.6	1.568	1.22	0.156	----	0.031	----
Plastics	5.35	5.24	3.14	0.377	1.72	----	----
Textile	4.1	3.69	2.03	0.24	1.15	0.17	0.005
Sum	88.03	39.328	19.88	2.583	14.27	0.756	0.102

Table 5: Organic components of MSW, USA [17].

Percent by weight, U.S. (kg)

Organic Components	Wet weight (kg)	Dry weight(kg)	Carbon (C)	Hydrogen (H)	Oxygen (O)	Nitrogen (N)	Sulfur (S)
Food Waste	15	4.5	2.16	0.29	1.69	0.12	0.02
Paper	45	42.3	18.4	3.54	18.61	0.13	0.08
Cardboard	10	9.5	4.18	0.56	4.24	0.03	0.02
Plastics	10	9.8	5.88	0.71	2.23	----	----
Yard Trimming	10	4	1.91	0.24	1.52	0.14	0.01
Wood	5	4	1.98	0.24	1.71	0.01	----
Sum	95	74.1	34.51	4.58	30	0.43	0.13

configurations, with and without sulfur for all three-sample data. Horizontal axis represents MSW combustible elements of carbon, hydrogen, oxygen, nitrogen, and sulfur which have been assigned value from 1 to 5, respectively. After having chemical formula for each configuration, now it is time to calculate heat value based on combustible component of MSW. Tehran Sample data 1, without Sulfur

$C_{32.28}H_{137.96}O_{60.74}N$. (2)

Tehran Sample data 1, with Sulfur

$C_{581}H_{248.33}O_{1093.33}N_{18}S$. (3)

Tehran Sample data 2, without Sulfur

$C_{30.74}H_{148.15}O_{66.67}N$. (4)

Tehran Sample data 2, with Sulfur

Table 6: Atomic weight and Numbers of Molls, Tehran Sample data 1.

Waste Compon-ents	Moisture	Carbon (C)	Hydrogen (H)	Oxygen (O)	Nitrogen (N)	Sulfur (S)
Kg	0	20.91	2.68	14.35	0.709	0.1
Kg	42.9	20.91	7.45	52.49	0.709	0.1
% Weight		25.1	8.94	63	0.9	0.12
Atomic weight		12	1	16	14	32.06
Number of Molls		1.743	7.45	3.28	0.054	0.003

Table 7: Atomic weight and Numbers of Molls, Tehran Sample data 2.

Waste Compon-ents	Moisture	Carbon (C)	Hydrogen (H)	Oxygen (O)	Nitrogen (N)	Sulfur (S)
Kg	0	19.88	2.583	14.27	0.756	0.1
Kg	48.7	19.88	8	57.56	0.756	0.1
% Weight		22.58	9.1	65.38	0.86	0.11
Atomic weight		12	1	16	14	32.06
Number of Molls		1.66	8	3.6	0.054	0.003

$C_{553.33}H_{2666.67}O_{1200}N_{18}S$. (5)

USA sample data, without Sulfur

$C_{92.68}H_{222.58}O_{98.71}N$. (6)

USA sample data, with Sulfur

$C_{718.25}H_{1725}O_{759}N_{7.75}S$. (7)

Calculating Heat Value

Based on Dulongs equation presented in Eq.1 below, heat value of MSW has been calculated for each set of data. (See S.I.7)

$$E = 337*C + 1428\left(H - \frac{O}{8}\right) + 9*S.$$

Tehran Sample data 1,

$$HV = 337*C+1428*(H-(\frac{O}{8}))+9*S = 9981\ \frac{KJ}{KG}. \quad (8)$$

Tehran Sample data 2,

$$HV = 337*C+1428*(H-(\frac{O}{8}))+9*S = 8935\frac{KJ}{KG}. \quad (9)$$

USA Sample data,

$$HV = 337*C+1428*(H-(\frac{O}{8}))+9*S = 13480\frac{KJ}{KG}. \quad (10)$$

Conclusion

Less infra-structure to separate waste at the origin in developing countries, such as Iran and higher amount of food waste component at the residential areas leads to higher municipal solid waste density in comparison to advanced countries such as USA. In Iran the density of MSW is at the range of 250 kg/m^3 to 400 kg/m^3 but in USA it is at the range of 100 kg/m^3 to 170 kg/m^3 [17]. It is mainly due to higher moisture content available in developing countries. As you can see in this study for three set of data based on S.I.2 moisture content has been calculated and provided below. Tehran set 1, has moisture content of 42.9 kg, Tehran set 2, has moisture content of 48.702 kg, and finally USA sample has moisture content of 20.9 kg, which is almost half of two previous samples from Tehran MSW. Heat value of MSW is highly dependent on moisture content because the higher the moisture content the less the heat value [17]. This is mainly due to hygroscopic nature of compost materials (BOD/COD). Thus, added water increases the weight, with no added nutrient value. Heat value

Table 8: Atomic weight and Numbers of Molls, USA.

Waste Components	Moisture	Carbon (C)	Hydrogen (H)	Oxygen (O)	Nitrogen (N)	Sulfur (S)
Kg	0	34.51	4.58	30	0.43	0.13
Kg	20.9	34.51	6.9	48.58	0.43	0.13
% Weight		36.33	7.26	51.14	0.45	0.14
Atomic weight		12	1	16	14	32.06
Number of Molls		2.873	6.9	3.036	0.031	0.004

Table 9: Number of molls with and without Sulfur, Tehran Sample data 1.

Elements	Carbon (C)	Hydrogen (H)	Oxygen (O)	Nitrogen (N)	Sulfur (S)
Number of moles	1.743	7.45	3.28	0.054	0.003
Number of moles without Sulfur	32.28	137.96	60.74	**1**	**0**
Number of moles with Sulfur	581	2483.33	1093.33	18	**1**

Table 10: Number of molls with and without Sulfur, Tehran Sample data 2.

Elements	Carbon (C)	Hydrogen (H)	Oxygen (O)	Nitrogen (N)	Sulfur (S)
Number of moles	1.66	8	3.6	0.054	0.003
Number of moles without Sulfur	30.74	148.15	66.67	1	0
Number of moles with Sulfur	553.33	2666.67	1200	18	1

Table 11. Number of molls with and without Sulfur, USA.

Elements	Carbon (C)	Hydrogen (H)	Oxygen (O)	Nitrogen (N)	Sulfur (S)
Number of moles	2.873	6.9	3.036	0.031	0.004
Number of moles without Sulfur	92.68	222.58	98.71	1	0
Number of moles with Sulfur	718.25	1725	759	7.75	1

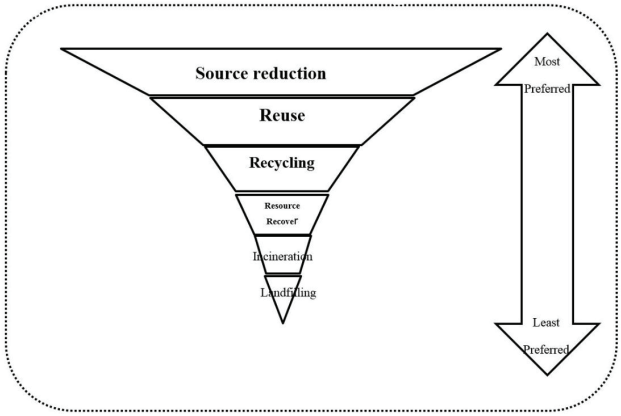

Figure 3: Hierarchy of solid waste management.

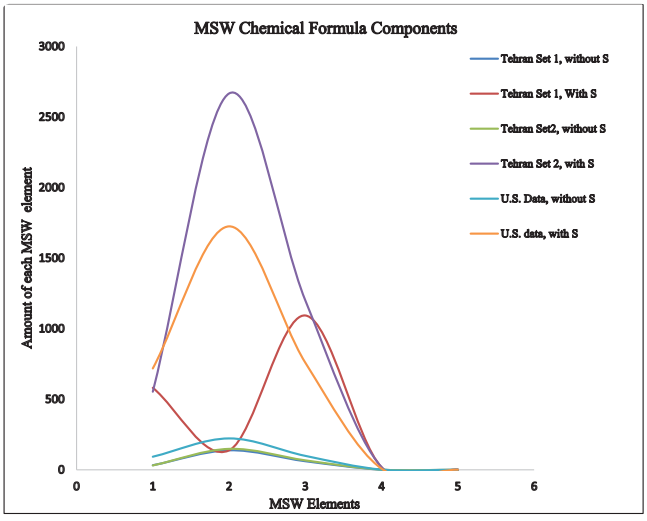

Figure 4: Municipal Solid Waste elements in both configurations for all three samples.

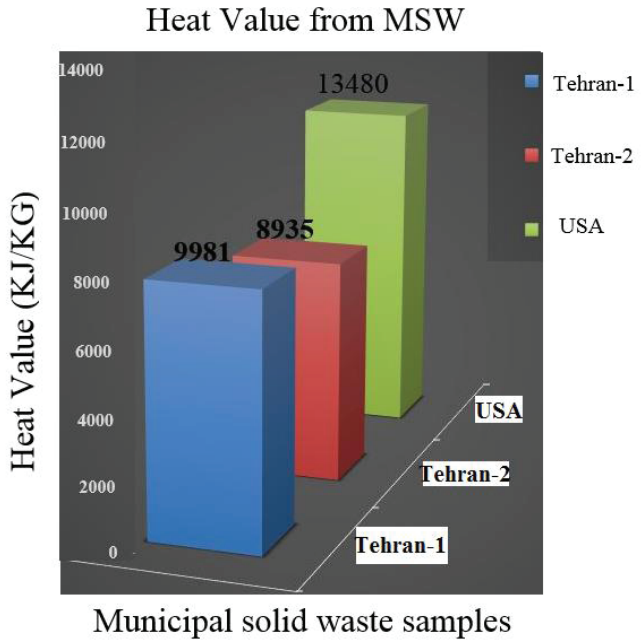

Figure 5: Heat value of three sets of data.

of three sets of data presented in (Figure 5) Showed the two close values for Tehran MSW samples and higher heat value for USA, which also indicates that the higher the moisture content the less the heat value of MSW.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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