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Prediction of the energy content of the municipal solid waste

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ABSTRACT

Aims: In this study, the amount, composition, and energy content of waste in Isfahan, Iran, were examined.

Materials and Methods: A time series model was used to predict the amount of waste generation in the future. The past waste changes was the basis for predicting how and to what extent the components will chnage. The energy content of mixed waste was calculated by the common heating value of each component and Dulonge's formula.

Results: The estimation of the amount of waste generated in Isfahan showed that the amount of organic materials would reduce to 59.1% and plastic materials would increase to 24.44%. Heating values of mixed waste, coarse, and fine reject based on dry weight were estimated in the first method as 3230, 1911, and 370 MWh per day, respectively, and as 2656, 1160, and 329 MWh per day, respectively, using Dulong's formula for the year 2019.

Conclusions: The results showed that by separating the combustible part of the waste and incinerating it, a remarkable amount of energy would be produced from waste in Isfahan resulting in the reduction of required landfill space and greenhouse gas emissions.

Key words: Energy content, incineration, Isfahan city, solid waste forecast

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INTRODUCTION

Enhancement of living standards, improvement of economic status, and industrial development have resulted in generation of a large amount of waste.[1] Human activities yield solid waste which has changed a lot due to the changes in lifestyle and comprehensive development.[2] There are many ways for waste management. The technology used for waste management depends on the type and amount of waste.[3] The processes for conversion of waste to energy (WTE) recover the energy from waste through direct combustion (e.g., incineration, pyrolysis, and gasification) or produce combustible fuels such as hydrogen, methane, and other synthetic fuels (e.g., anerobic digestion, biological treatment, and refuse-derived fuel).[4] The processes for conversion of waste to energy can shorten the landfill site by reducing the volume of the waste and can also reduce the need for fossil fuels and emission of greenhouse gases (GHG). According to American Environmental Protection Agency's (EPA) report, waste energy is considered a renewable source of energy.[5]

Research Deputy of Isfahan decided to study and choose

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optimum method(s) of processing and disposing of general waste in the city. Isfahan, located in east longitude of 51 degrees, 39 minutes, and 40 seconds, north latitude of 32 degrees, 38 minutes, and 30 seconds, and an altitude of 1575 m above sea level, is the center of Isfahan Province. Meteorological statistics of Isfahan over the past 30 years show that the maximum rainfall with an average of 21.7 mm and minimum rainfall with an average of 0.1 mm took place in April and September, respectively. Moreover, the maximum temperature with the average of 29.1°C and the minimum temperature with the average of 3.9°C were in July and January, respectively.

MATERIAL AND METHODS

Isfahan's population was 1745,428 people in 2009. This city has 14 municipal regions and a mean family size of 3.6. The population is expected to be 2394,815 people in 2026.[6]

Calculation of the amount of waste generation

Time series were used to make predictions for the amount of waste generation. ARMA procedure was used to fit the model.[7]

Calculation of the waste's components

Data related to the previous years were collected from the Organization for Waste Recycling and Conversion to determine general waste's components. Physical analysis of waste was carried out according to standard methods.[8] Prediction of the way and rate of changes in waste components was made based on the changes occurring before years and the results were compared with credible relevant resources.[6]

Calculation of the amount of coarse and fine rejects in organic fertilizer production line

Estimation of the amount of waste generation was done according to the factory input waste weight, wastes of coarse and fine reject production line. Coarse and fine reject wastes comprised 30% and 7% of the input waste, respectively.

Heating value estimation approach

The energy content of waste in Isfahan was obtained for the three forms of waste: (1) mixed waste (including all components of the waste), (2) combustible waste (wastes from coarse rejects of production line), and (3) combustible waste or waste suitable for landfills (wastes from fine rejects of production line) by two methods. In the first method, the common heating value of each waste component was obtained based on the method provided by integrated solid waste management book. In this method, the amount of each waste component was determined by multiplication of each component's dry weight by its energy content. In the second method, estimation of the heating value was based on the waste chemical composition by Dulonge's formula.[8]

RESULTS

The results on the estimation of the amount of waste generation during previous years and in future in Isfahan were provided in Table 1. Waste generation of 825 tons per day in 2004 increased to 1069 tons in 2010, i.e. the amount of waste generation had an upward trend during these years, except for 2007. However, this upward trend had a high rate in 2006. The mean growth rate of waste generation was 3.39% during these years. The amount of waste generation would be 1103 tons with the growth rate of 4.48% in 2012. This rate would be 3.48% with the amount of waste generation of 1500 tons in a downward trend in 2020.[7] Table 2 shows the waste physical analysis for various years. Significant changes were related to organic materials and plastics. The amount of organic materials of 83.31% in 1994 reduced to 65.77% in 2011. However, the amount of plastics of 4.28% in 1994 increased to 18.14% in 2011. Furthermore, the amount of textiles, rubber, metals, ash, and soil increased and the amount of glass, wood, and green waste decreased during this period.

The rate of change in each waste component from 2012 to 2020 was shown in Table 3. Increasing and decreasing growth rate of each component was determined based on the change rate of that component since 1994 and the standards provided in reliable resources. Predictions showed that the amount of organic materials, wood, glass, metals, soil, and trash comprised 1.1%, 2%, 0.9%, 2%, and 2%, respectively, in a downward trend, and the amount of plastics, paper and cardboard, textiles, and rubber and leather comprised 4%, 2.5%, 2%, and 1%, respectively, in an upward trend. Predictions based on the waste wet weight for the different types of waste generated during the following years up to 2020 are shown in Table 4. These data were obtained by multiplication of the amount of waste generated during

Table 1: The amount of general waste during different years in Isfahan

Year	Amount (Ton/day)	Growth rate than the previous year
2003	804.91	-
2004	824.65	2.45
2005	856.18	3.82
2006	889.49	3.89
2007	878.23	-1.27
2008	980.88	11.69
2009	1029.72	4.98
2010	1069.20	3.83
2011	1103.19	3.18
2012	1147.43	4.01
2013	1191.68	3.86
2014	1235.91	3.71
2015	1280.16	3.58
2016	1324.40	3.46
2017	1368.63	3.34
2018	1412.88	3.23
2019	1457.11	3.13
2020	1501.36	3.04

various years by predicted percentage of each component.

Physical analysis performed on the wastes of coarse reject production line after baling waste in Isfahan organic fertilizer factory is shown in Figure 1. Results showed that plastics comprised the maximum amount of 52.9% of the waste. Textiles and organic materials followed plastics comprising 18% and 14.5% of the waste, respectively. 14.6% of the waste was other materials. Table 5 shows the amount of waste generated in coarse reject production line. The calculations were done assuming that 30% of the input waste converted into the wastes of coarse reject production line. Physical analysis performed on the wastes of fine reject production line in Isfahan organic fertilizer factory is shown in Figure 2. Results showed that plastics comprised the maximum amount of 29.31% of the waste. Textiles, organic materials, and paper and cardboard which followed plastics comprised 20%, 22.41%, and 12% of the waste, respectively. 16.21% of the waste was other materials. Table 6 shows the amount of waste generated in fine reject production line. The calculations were done assuming that 7% of the input waste converted into the wastes of fine reject production line.

In the first method, heating values estimated for the general waste, coarse and fine reject wastes based on their dry weights are shown in Figure 3. The heating value for the general waste was estimated to be 2282 MWh per day in 2012 and 3230 MWh per day in 2020. The heating value for the coarse reject waste was estimated to be 1627 MWh per day in 2012 and 1911 MWh per day in 2020. The heating value for the incinerated fine reject waste was estimated to be 314 MWh per day in 2012 and 370 MWh per day in 2020.

Chemical formulas had to be obtained prior to the calculation of heating value. Chemical formulas are shown in Table 7. The heating value for the general waste was estimated to be 2163 MWh per day in 2012 and 2656 MWh per day in 2020. The heating value for the coarse reject waste was estimated to be 988 MWh per day in 2012 and 1160 MWh per day in 2020. The heating value for the incinerated fine reject waste was estimated to be 280 MWh per day in 2012 and 329 MWh per day in 2019 [Figure 4].

Table 2: Physical analysis of municipal solid waste in Isfahan (percent)

Year	1994	2005	2006	2007	2009	2010	2011
Municipal solid-waste composition							
Organic material	83.31	73.15	72.31	68.90	79.60	68.98	65.77
Paper and cardboard	2.34	4.19	5.51	6.43	3.90	4.87	4.34
Plastics	4.28	11.26	9.84	13.73	9.40	14.79	18.14
Textiles	2.07	4.50	5.88	4.12	4.10	4.79	3.99
Rubber and leather	0.15	0.17	0.16	0.17	0.20	0.37	0.97
Wood and green waste	1.04	1.82	1.80	1.20	0.80	0.85	0.63
Glass	2.13	1.90	1.55	2.55	1.00	1.17	1.09
Metals	2.27	1.50	1.41	1.40	0.60	1.70	2.48
Soil, ash, etc.	2.41	1.51	1.54	1.50	0.40	2.50	2.60

Table 3: Prediction of municipal solid waste compositions in coming years in Isfahan (percent)

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
Waste's composition									
Organic material	65.00	64.11	63.40	62.49	61.80	61.00	60.30	59.10	58.70
Paper and cardboard	4.50	4.59	4.70	4.82	4.91	5.00	5.13	5.25	5.04
Plastics	19.00	19.85	20.47	21.29	22.00	22.80	23.50	24.44	23.22
Textiles	4.00	4.08	4.16	4.24	4.30	4.39	4.47	4.56	4.03
Rubber and leather	0.98	0.99	1.00	1.01	1.02	1.03	1.04	1.05	1.01
Wood and green waste	0.60	0.59	0.58	0.56	0.55	0.54	0.53	0.52	0.62
Glass	1.00	0.99	0.98	0.97	0.96	0.96	0.95	0.94	1.07
Metals	2.42	2.37	2.32	2.28	2.20	2.14	2.10	2.06	2.51
Soil, ash, etc.	2.50	2.43	2.38	2.33	2.25	2.19	2.15	2.10	2.87

Table 4: Prediction of the amount of municipal solid waste compositions based on their wet weight in different years in Isfahan (kg per day)

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
Waste's composition									
Organic material	737.69	757.48	776.71	795.42	813.60	831.27	848.44	865.10	881.29
Paper and cardboard	51.30	54.08	56.93	59.85	62.85	65.92	69.08	72.31	75.62
Plastics	218.71	232.82	247.50	262.77	278.65	295.16	312.32	330.14	348.67
Textiles	45.86	47.68	49.50	51.33	53.17	55.01	56.85	58.69	60.55
Rubber and leather	11.22	11.70	12.18	12.67	13.16	13.65	14.15	14.65	15.16
Wood and green waste	7.21	7.48	7.75	8.02	8.29	8.56	8.82	9.09	9.35
Glass	12.43	12.89	13.36	13.82	14.28	14.75	15.21	15.67	16.13
Metals	28.49	29.64	30.79	31.94	33.10	34.26	35.43	36.59	37.77
Soil, ash, etc.	30.43	31.92	33.44	34.98	36.55	38.15	39.78	41.43	43.12

DISCUSSIONS

The amount of waste generation affects the waste management system from the point of generation to the landfill in determining dimensions and volume of required containers, method of storage, collection, transfer, and choice of an effective technology for disposal of waste. In this study, the focus was on choosing the way of waste processing and disposal. The amount of waste generation in Isfahan is shown in Table 1. Waste generation rate will become 1501 tons per day in 2020. The results showed that the growth rate of waste would decrease in the coming years. The report on the amount of waste generation during 1960 to 2009 by EPA showed that the amount of waste generation of 88.1 million tons a year increased to 255 million tons a year, and the amount of waste generation per capita of 2.68 pounds a day increased to 4.63 pounds a day. However, the amount of waste generation was 243 million tons a year and waste generation per capita was 4.34 pounds a day in 2009. This reduction was due to the prevention of waste generation and the subsequent decrease.[9] The results by the above report conformed to the present study results.

The type of waste may affect the method and technology of processing and disposing. Physical analysis of waste is shown in Table 2. Organic materials, plastics, paper and cardboard, and textiles comprised 59.1%, 24.4%, 5.25%, and 4.56% of the total waste, respectively. All the three combustible forms of the waste had upward trends. The percentage of organic materials was still higher than those of the developed countries. Therefore, exploring the method of processing and disposal of organic materials besides composting methods of digestion, vermicomposting, production of animal feed, etc. is of special importance considering environmental rules, economical condition, climate, and energy status. Moreover, proper technologies must be studied for extracting energy from the materials with high heating value which are currently landfilled. The report on the amount of waste generation during 1960 to 2009 by EPA showed that the amount of paper and cardboard of 34% increased to 36.2% of the total waste, while applying prevention methods, the amount decreased to 28.2% in 2009. Furthermore, the plastics amount of 0.4% increased to 12.3% since 1960. Rubber and leather, textiles, and food wastes comprised 2.1%, 2%, and 13.8% in 1960 which increased to 3.1%, 5.2%, and 14.1% in 2009, respectively. Except for the paper and cardboard waste which had a downward trend during the later years, other waste components had upward trends.[9] These results conformed to the present study results.

Materials larger than 5 cm comprised the wastes of coarse

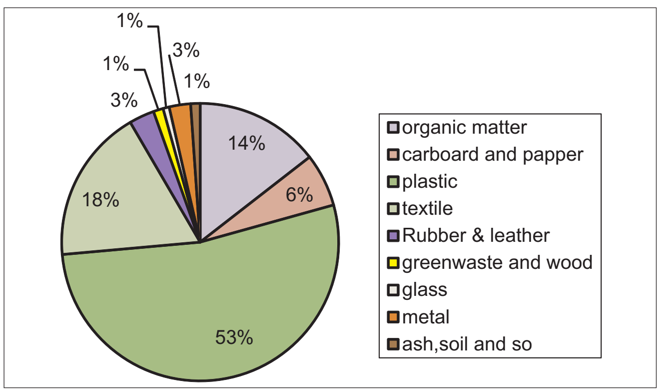

Figure 1: Physical analysis mean for the wet weight of coarse reject wastes production line after baling waste in Isfahan Compost Plant

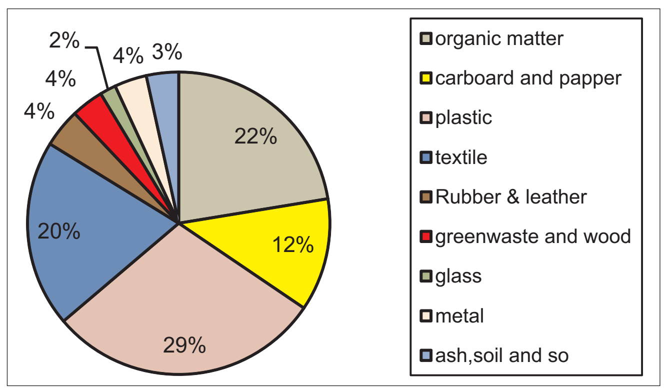

Figure 2: Physical analysis mean for the wet weight of fine reject wastes production line in Isfahan Compost Plant

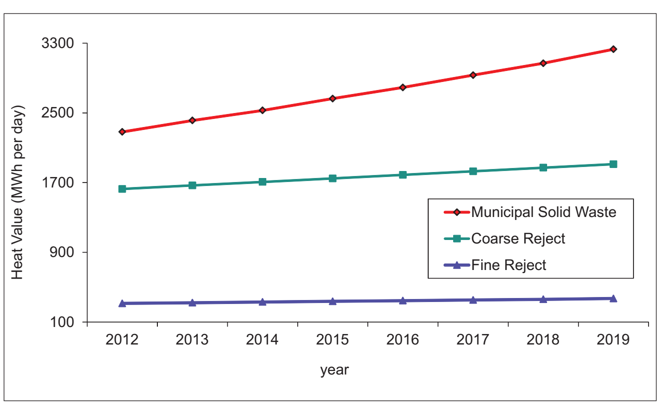

Figure 3: Heating value estimation based on the dry weights using the amount in reference 8 (MWh per day)

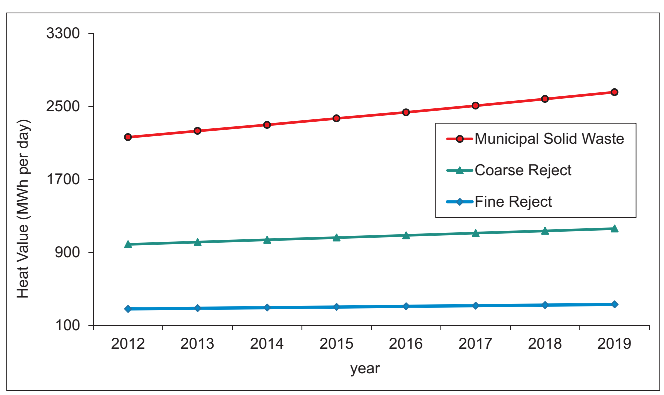

Figure 4: Heating value estimation based on the dry weights using Dulong's formula (MWh per day)

Table 5: Prediction of the amount of waste components of coarse reject based on their wet weight in different years in Isfahan (kg per day)

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
Waste's composition									
Organic material	40,792	41,837	42,882	43,928	44,973	46,018	47,063	48,108	49,154
Paper and cardboard	17,414	17,860	18,306	18,753	19,199	19,645	20,091	20,537	20,983
Plastics	148,820	152,633	156,447	160,260	164,073	167,886	171,699	175,513	179,326
Textiles	50,638	51,936	53,233	54,531	55,828	57,126	58,423	59,721	61,018
Rubber and leather	8,299	8,512	8,724	8,937	9,150	9,362	9,575	9,788	10,000
Wood and green waste	3,235	3,318	3,401	3,484	3,567	3,650	3,733	3,815	3,898
Glass	2,026	2,077	2,129	2,181	2,233	2,285	2,337	2,389	2,441
Metals	7,033	7,213	7,394	7,574	7,754	7,934	8,114	8,295	8,475
Soil, ash, etc.	3,095	3,174	3,253	3,332	3,412	3,491	3,570	3,650	3,729

Table 6: Prediction of the amount of waste's components of fine reject based on their wet weight in different years in Isfahan (ton per day)

Year	2012	2013	2014	2015	2016	2017	2018	2019	2020
Waste's composition									
Organic material	14,710	15,087	15,464	15,841	16,218	16,595	16,972	17,349	17,726
Paper and cardboard	7,923	8,126	8,329	8,532	8,735	8,938	9,141	9,344	9,547
Plastics	19,240	19,733	20,226	20,719	21,212	21,705	22,198	22,691	23,184
Textiles	13,128	13,465	13,801	14,138	14,474	14,810	15,147	15,483	15,820
Rubber and leather	2,718	2,787	2,857	2,926	2,996	3,066	3,135	3,205	3,275
Wood and green waste	2,265	2,323	2,381	2,439	2,497	2,555	2,613	2,671	2,729
Glass	1,129	1,158	1,187	1,216	1,245	1,274	1,303	1,332	1,360
Metals	2,265	2,323	2,381	2,439	2,497	2,555	2,613	2,671	2,729
Soil, ash, etc.	2,265	2,323	2,381	2,439	2,497	2,555	2,613	2,671	2,729

Table 7: Calculation of the chemical formula for the municipal solid waste, coarse, and fine reject wastes in Isfahan Compost Plant

Type of material	With sulfur		Without sulfur	
	With water	Without water	With water	Without water
General waste	$C_{25.64}H_{39.11}O_{14.73}N$	$C_{25.64}H_{64.92}O_{26.95}N$	$C_{452.91}H_{690.72}O_{260.11}N_{17.66}S$	$C_{452.91}H_{1146.59}O_{476}N_{17.66}S$
Fine reject waste	$C_{24.98}H_{37.4}O_{13.32}N$	$C_{24.98}H_{62.09}O_{24.37}N$	$C_{596.27}H_{892.72}O_{317.79}N_{23.87}S$	$C_{596.27}H_{1481.91}O_{581.56}N_{23.87}S$
Coarse reject waste	$C_{25.98}H_{38.45}O_{14.71}N$	$C_{25.98}H_{63.82}O_{26.92}N$	$C_{637.2}H_{942.93}O_{360.77}N_{24.53}S$	$C_{637.2}H_{1565.27}O_{660.22}N_{24.53}S$

reject production line. After the separated materials pressed and baled, they were delivered to the landfill site. Physical analysis showed that plastics, textiles, and organic materials comprised the 52.9%, 18% and 14.5% of the total waste, respectively. 14.6% of the waste was the other materials. It was found that a large percentage of these wastes were materials with high heating value which comprised 30% of the weight of the factory's input total general waste. Therefore, studying technologies for conversion of waste to energy is necessary. As the coarse reject generated in composting factory had impurities, it was sieved again with a sieve of 1.8 cm mesh before using in green space or agriculture, and this operation left some waste. Physical analysis showed that plastics, textiles, organic materials, and paper and cardboard comprised 29.31%, 20%, 22.41%, and 12% of the total waste, respectively. 16.21% of the waste was other materials. These components comprised 7% of the weight of the factory's input total waste. These wastes are currently landfilled, although they have a high heating value and are of special importance for converting them into energy.

Thermal processing of waste is an important factor in many comprehensive waste-management systems. In this process, heating energy is released simultaneously or subsequent to the conversion of waste to gas, liquid, and solid.[8] The heating value must be measured to use waste in processing. There are two methods for measuring the heating value. In the first method, heating values estimated for the general waste, coarse, and fine reject wastes based on their dry weights were estimated to be 3230 MWh, 1911 MWh, and 370 MWh per day, respectively, in 2020. In the second method using Dulong's formula, heating values estimated for the general waste, coarse, and fine reject wastes based on their dry weights were estimated to be 2656 MWh, 1160 MWh, and 329 MWh per day, respectively, in 2020. Heating values obtained using the second method were lower than those of the first method. Although coarse reject wastes comprised 30% of the total waste, heating values obtained through the first and second methods comprised 59% and 44% of the total waste's heating value, respectively. The heating value of fine reject wastes comprised 12% of the total waste's heating value, whereas it comprised 7% of the total waste's weight.

The heating values measured using Dulong's formula for general waste, coarse, and fine reject wastes were 14,500 kj/kg, 14,681 kj/kg, and 15,925 kj/kg, respectively, in 2020. Estimations done on the waste in Tehran, Iran, showed an approximate heating value of 8700 kj/kg. [10] A study by Omrani *et al*, on the waste chemical properties in Sistan-Baloochestan Province, Iran, showed the heating value of 11,883 kj/kg based on the waste dry weight in 2003.[2] The waste heating value is 17,000 kj/kg – 8400 kj/kg in European and American countries. [11] Chemical formulas obtained with water and sulfur on the basis of waste composition for general waste, coarse, and fine reject were $C_{452.91}H_{1146.59}O_{476}N_{17.66}S$, $C_{596.27}H_{1481.91}O_{581.56}N_{23.87}S$, and $C_{596.27}H_{1481.91}O_{581.56}N_{23.87}S$, respectively, in 2019. The chemical formula obtained for the waste of Sistan-Baloochestan Province, Iran, by Omrani *et al.* was C487H1142O486N15S. [2]

It can be concluded that the waste growth rate will decrease in coming years. The percentage of combustible waste components like plastics, paper and cardboard, etc. will increase, and the percentage of organic materials will decrease. Therefore, it is necessary to choose a proper method of waste management. The heating value of general waste especially in compost plants (often the combustible materials) is high. It is worth measuring the heating values using the bomb calorimetry method and comparing them with the values obtained in the present study. Furthermore, suitable technologies must be studied for extracting energy from these types of waste. Other methods for managing organic material waste besides composting should be explored regarding the present conditions and future changes. Conversion of waste to energy can solve the problem of waste disposal, recover waste energy, and be used in generating electricity, fuels and gases. Pollution emissions may decrease using appropriate control equipment, sites for hygienic landfilling and the amount of green gas emissions will decrease as well.

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