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A comprehensive study on municipal solid waste characteristics for green energy recovery in Urta-Chirchik: A case study of Tashkent region

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ABSTRACT

This study aimed to investigate the characteristics and composition of MSW generated in one of the biggest districts (Urta-Chirchik) of the Tashkent Region. The results indicated that the wood waste level was the highest among other components of MSW. Hence, the MSW samples were divided into two groups: a) mixed MSW and b) wood waste. Proximate and ultimate analyses of the samples were investigated following the ASTM and European Pn-En international standards. A study of energy recovery was conducted using a bomb calorimeter (model: V-08 MA) and ASTM standards. The energy content or calorific value of the mixed MSW was 2479.34 kcal/kg and 2190.02 kcal/kg for wood waste respectively. The elemental analysis of the samples was performed by CHNS/O elemental analyzer. The XRF results showed that MSW and wood wastes contain mainly CaO, SiO_2, Fe_2O_3 and other 15 combining oxides. It has been observed that MSW is less reactive to combustion as compared to coal, but its reactivity can be improved through the pre-treating process so as to reduce noncombustible materials such as oxygen and ash content. In addition, an introduction of updated thermochemical conversion of MSW to value-added products and robust Waste-to-Energy technological project development is recommended.

Selection and peer-review under responsibility of the scientific committee of the 7th International Conference on Nanomaterials and Advanced Energy Storage Systems.

1. Introduction

The need to save energy and reduce environmental pollution lead us to the more rational use of traditional energy resources, as well as looking for other, preferably renewable and inexpensive energy sources. Municipal solid waste (MSW) is one of the renewable energy sources which have recently attracted profound attention of not only the research community but also municipalities [1]. MSW has both direct and indirect effects on the environment and human well-being [2]. Direct effects range from damage to materials and loss of aesthetic importance to human health, thereby creating significant socio-economic consequences. Indirect effects are mainly long-term effects, which vary from changes in the ecosystem structure and behavior to climate change, which in turn will affect the social economy and sustainability of the region [3]. At landfills, biodegradable components of MSW (for example, food waste) decompose and emit methane - a greenhouse gas that is 23 times stronger than carbon dioxide, and causes significant environmental problems. Other components (for example, a lixiviant) can also cause significant environmental pollution in the air and groundwater and cause a toxic odor. In addition, an open MSW dump generates other toxic gases when it is unintentionally burned. For these reasons, most countries seek to reduce their dependence on the use of landfills for MSW [4,5]. Municipal wastes, which are formed in significant quantities and which, as a rule, cannot be used and pollutes the environment, are renewable secondary energy resources. The energy extracted from the waste can be used to produce heat or electricity. At the same time, the use of MSW in the energy sector allows solving actual problems of environmental pollution in urban areas and obtaining additional sources of energy [1,6].

Uzbekistan is the only country with the highest population (more than 32 mln) in Central Asia. Consequently, the amounts of generated MSW are much higher in comparison with other Central Asian countries. Nevertheless, MS. In the Republic of Uzbekistan, as well as throughout the world, there are acute issues of safe solid waste disposal. According to the State Committee Statistics of the Republic of Uzbekistan, 35 million cubic meters of municipal solid waste are produced annually in the republic. In addition, the annual 100 million tons of industrial waste require

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disposal, which so far is simply collected on landfills. To date, 2 billion tons of waste has accumulated in the country [7,8].

Thermal treatment process is more and more frequently used to neutralize wastes as it allows for energy recovery and for the reduction of the solid mass of original wastes by 70% and their volume by up to 90% [9,10]. The current methods of waste thermal treatment are considered as very effective, but they also generate significant amounts of undesirable by-products (e.g. ash, tar, volatile compounds etc.). All those by-products have to be vigilantly managed not to pose a threat not only to the environment but also to the mankind. Basically, they are placed in landfills or recycled. A number of developed countries have already adopted their policies towards the reduction of the number of landfills and simultaneous development of contemporary methods of waste recycling [11].

Due to the significant amounts of wastes and the fact that their composition varies, one must first determine their specific properties by virtue of advanced examination methods and on that basis apply the most appropriate neutralization technology. Hence, this study aims to comprehensively study specific properties and characteristics of MSW generated at Urta-Chirchik district landfill.

2. Experimental

This research methodology consists of sampling selection method, sorting procedure and laboratory analysis to determine proximate, ultimate and compositional analysis of the MSW accommodated at Urta-Chirchik landfill in Tashkent region of Uzbekistan. Generally, there are two formal types of sampling and analysis methods based on ASTM D 5231–5292 and European Standard PN-EN [12].

Accordingly, this research methodology will help for management categories in order to improve MSW treatment and energy extraction routes by identifying recycling opportunities, promoting waste abatement efforts or isolating specific fractions as well.

2.1. MSW biomass sampling

The procedure was applied for collecting the representative of MSW based on the American Society for Testing and Materials (ASTM). The sampling took place in January 2019 and was pick up of the four large garbage bag from waste landfill at Urta-Chirch (Tashkent region) which is usually an amount of 20 or 25 kg/per garbage bag (total: ~100 kg) and thoroughly investigated at the research laboratory under the Department of Power Supply and Renewable Energy Sources, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers. Next, the waste was separated according to the selected classification and the MSW samples were a mixture of ten different components of wood, kitchen garbage, plastic bag, solid plastic, textile, glass, rubber, ferrous materials and others. Each category was weighted by using a weight balance and the materials were discarded after recording the data.

As wood components of MSW resulted to higher percentage compared with other MSW components (see result section for more details), some amount of it were picked in order to conduct a separate characteristic analysis for wood waste biomass sample as well. Hence, the investigation was carried out on two sample categories: MSW and wood waste biomass.

2.2. Proximate analysis

Proximate analysis consists of moisture content determination and afterward, for dry biomass sample, determination of ash content, volatile matter. In this study, the laboratory tests for measuring the proximate analysis of waste biomass samples were conducted based on European PN-EN and ASTM standards.

Moisture content. The percent of moisture content in waste biomass was first determined by letting the samples to dry at room temperature of ~20 °C for seven days, and then weighting the samples into dish and drying in oven at 105 °C for 3–4 h after which it was cooled at normal room temperature and then reweighted to constant weight. The procedure for moisture content determination was done following European PN-EN 14774-3:2010 and ASTM-E871 standards [13–15].

Volatile matter content. The volatile matter content was determined by the method of 5 g MSW and 1 g wood waste samples ignition at 950 °C for MSW and 900 °C for wood waste, following Furnace Thermocouple Thermo-junction (FTT) method - European PN-EN 15148–3:2010.900 standard [12,14,16,17].

Ash and fixed carbon content. Ash content of waste biomass is a non-combustible residue left after the waste biomass is burn up, which represents the natural substances after carbon, oxygen, sulfur and water. Analysis include of MSW and wood biomass samples were taken in duplicate of 5 g (for MSW) and >0.1 g/cm^2 (for wood), and ignited to heat up to 400 °C with gradual increase in temperature of the muffle furnace to 750 °C for MSW [18] and 500 ± 10 °C [12,17] for wood biomass for at least 60 min, according to European PN-EN 14775:2010 standard.

Fixed carbon (F_c) defined by carbon found in the material which is left after volatile test and its content is determined by removing the volatile matter, moisture and ash contents from the original mass of the biomass sample (Eq. (1)).

$$F_c\,(wt\%\ wet\ basis) = 100 - (M_c + Ash + V_m) \quad (1)$$

2.3. Ultimate analysis

Ultimate analysis was carried out to determine the CHNS/O content in MSW and wood biomass samples by using the Thermo Scientific™ FlashSmart™ Elemental Analyzer. Such analysis presents the weight percent of carbon (C), hydrogen (H), nitrogen (N), sulphur (S) and oxygen (O) in the sample simultaneously.

In addition to the ultimate analysis, surface characteristics for determination a complete oxide composition in HWS and wood waste biomass samples were also studied in order to profoundly perceive the chemical structure and characteristics of MSW and wood waste samples. PAN analytical X-ray fluorescence (XRF) spectrometer was applied for surface characteristics analysis to determine a complete oxide composition in the examining samples.

2.4. Energetic (calorific) value

Several factors including energetic /or heat value, waste composition, and the annual amount of waste affect the feasibility of reusing the waste as a fuel source. In this research study, heat/energetic values of municipal soild and wood wastes are measured to check the feasibility of energy recovery from the wastes.

Determination of the energetic value/or heating value of MSW and wood biomass samples can be investigated either by using mathematical models [19–23], structural and proximate analyses [24–28], as well as experimentally [12,16,17,29]. Experimental determination by using a bomb calorimeter utilize a sample size of 1 g or 2 g which is inadequate to account for the vast variance in waste biomass composition, thus requiring bigger sample size [16]. Moreover, the experimental method also requires technical skills in handling the equipment, and the combustion by products as well. As for the mathematical models, they were developed to avoid over reliance on lengthy experimental technique. In this study, amount of energetic (calorific) value was determined by using a bomb calorimeter (Model: V-08-M) (Fig. 1), following European PN-EN 14918:2010 and PN-ISO 1928 standards.

The temperature in the calorimetric shield was maintained constant to within ± 0.01 K. The electric energy spent to ignite the substance was measured through the discharge of the 9.0 mF capacitor bank, and the platinum wire of 0.05 mm is used for the ignition. The temperature of the calorimetric vessel is measured by the 100 W platinum resistance thermometer using the bridge pattern. The unbalance is registered with the digital Sch-1516 voltmeter with ± 0.0002 V uncertainty.

The electronic device for the automation of the measuring process was projected. The primary information was sent to the computer, and all the necessary calculations were made, such as corrections for heat exchange, energy of combustion of the substance and washburn corrections. The oxygen used to fill the bomb was purified in the apparatus with heated copper oxide (CuO), a pipe cooler and tube with ascarite. MSW and wood waste biomass samples in the form of pellets were weighed with accuracy of ± $2{\cdot}10^{-5}$ g. Next, the mass was reduced to vacuum.

The energetic (calorific, thermal) value of the samples calorimetric properties was determined from the following equation:

$$Q_w = Q_s - r/100 + \left(8.94H^a - W^a\right) \quad (2)$$

where:

Q_w – energetic (calorific value), kcal/kg; Q_s – heat of combustion; W^a – moisture content in the sample, %; H^a – hydrogen content in the sample, %; r – heat of water vaporization, r = 586.13 kcal.kg.

3. Results and discussions

3.1. Biomass sampling

The investigation for biomass sampling took place for about two months. The results from sorting process and quantity of each individual component of the MSW at UrtaChirchik landfill is highlighted in Fig. 1.

As Fig. 1 indicates MSW such as, wood, textile, kitchen garbage and plastic (film) bag make up the largest fraction of generated waste in Urta-Chirchik landfill. Top ten individual materials were most prevalent in the Urta-Chirchik disposed waste stream included of wood waste (47.9 wt%), textile (13 wt%), kitchen garbage (9.5 wt%), plastic (film) bag (8.9 wt%), solid (film) plastic (5.3 wt%), glasses (5.3 wt%), paper (4.7 wt%), rubber (2.4 wt%), ferrous materials (0.6 wt%) and other wastes (2.4 wt%).The great percentage of wood waste can be explained by the geographical location of the Urta-Chirchik region which is lack in tall building apartments; it is rather a suburban region where people reside in the ground houses. The reason why woody waste resulted to higher % among the other component of MSW, it is because the collection procedure took place in January just after the fall, harvesting, gardening, and construction seasons (in Uzbekistan fall season starts late). The wastes which were collected during these seasons from households and municipalities just mixed with the other types of wastes and dumped in landfill.

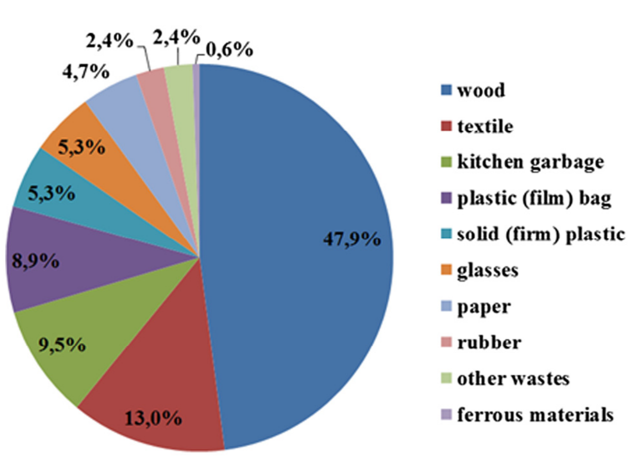

Fig. 1. Municipal solid waste composition at Urta-Chirchik landfill.

Increasing the population and also rapid industrialization since few years could be the main reason for amplification the quantity of MSW. Ferrous materials and other wastes had a small fraction of MSW in this landfill. High percentage of recyclable components demonstrates that the landfill in UrtaChirchik has vast potential for the recovery facilities, for instance "pyrolysis and gasification techniques". The recovery process can be considered as one of the acceptable rationale methods to decrease and handle the high volume of recyclable materials.

3.2. Proximate and ultimate analysis

Proximate analysis involves determination of moisture, volatile matter, ash and fixed carbon contents in selected samples. Ultimate analysis involves determination of chemical characteristics of examining sample. Hence, the results from proximate and ultimate analysis are shown in Table 1. In addition, a complete oxide composition in the samples was also determined to deeper understand the chemical structure and characteristics of MSW and wood waste samples, and the results are highlighted in Fig. 2.

Table 1 shows that the proximate and ultimate analysis of MSW and wood used in this study. It can be seen from the table that MSW has 13.05 wt% moisture and 3.55 wt% fixed carbon contents. The moisture and fixed carbon contents in the wood sample were 18.22 and 10.88 wt%, respectively. The moisture content is measured with the amount of water lost from materials upon drying to a constant weight, and it is directly affected by physical and chemical properties of material which enable it to absorb the exiting water in the environment [16,17]. Fixed carbon is the carbon remaining on surface as charcoal [12,16,17]. Table 1 highlights processed MSW has volatile matter 62.6 wt% and ash 20.8 wt% contents, while wood has 49.4 wt% of volatile matter and 21.5 wt% of ash contents. Both of these parameters have direct influence on the pyrolysis or gasification characteristics and performances. MSW and wood biomass are less reactive to combustion as compared to coal, but its reactivity can be improved through the pretreating process so as to reduce noncombustible materials such as oxygen and ash content [12,17].

Ultimate analysis demonstrates determination of chemical characteristics of biomass samples. The result of ultimate analysis that was investigated by Thermo Scientific™ FlashSmart™ Elemental Analyzer is also shown in Table 1. The sulfur (S) and nitrogen

Table 1
Proximate and Ultimate analysis of MSW and wood.

Proximate Analysis			
MSW		Wood	
Moisture, wt%	13.05	Moisture, wt%	18.22
Volatile matter, wt%	62.6	Volatile matter, wt%	49.4
Ash, wt%	20.8	Ash, wt%	21.5
Fixed carbon, wt%	3.55	Fixed carbon, wt%	10.88
Ultimate Analysis			
C, wt%	54.26	C, wt%	52.41
H, wt%	5.87	H, wt%	7.03
S, wt%	0.71	S, wt%	0.25
N, wt%	1.59	N, wt%	0.56
O, wt%	37.57	O, wt%	39.75

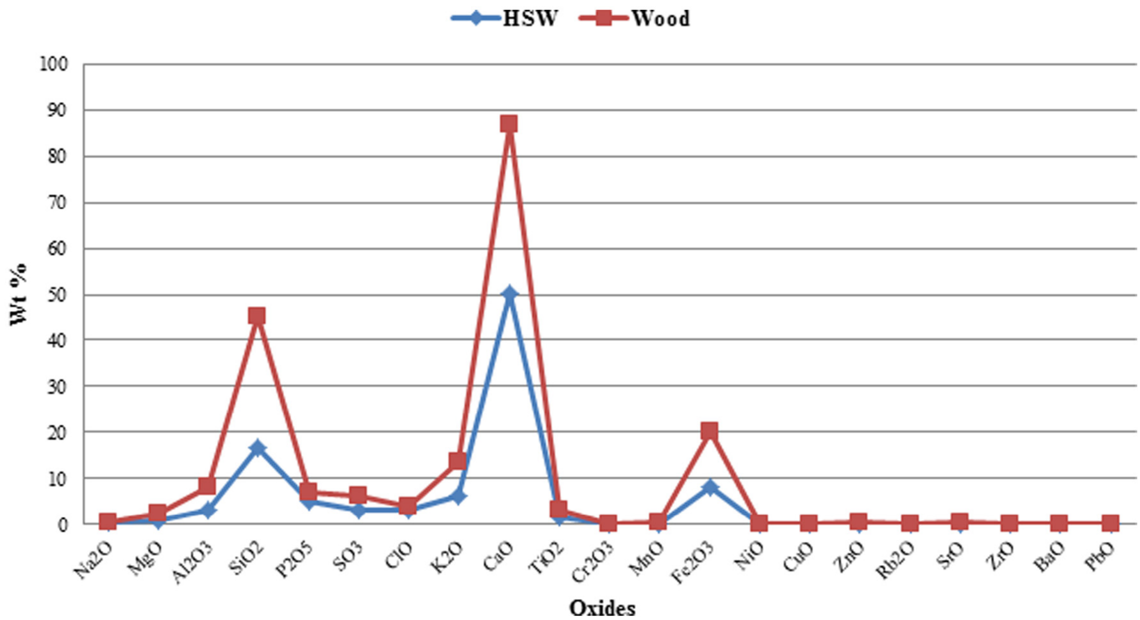

Fig. 2. XRF patterns of MSW and wood.

(N) are not high in all species studied, so it would not be a problem in biomass conversion technologies caused by this element. Fig. 3 and Table 2 highlight the XRF patterns obtained for MSW and wood biomass. It shows that both MSW and wood contain mainly CaO, SiO_2, Fe_2O_3, K_2O and 17other combining oxides.

3.3. Energetic (calorific) value

Fig. 3 illustrates the comparative analysis of energetic (calorific) value or high heating value (HHV) in each biomass samples. It can be noted that MSW has a slightly higher energetic value of 2479.34 kcal/kg comparing to wood which has energetic value of 2190.02 kcal/kg.

The main factor affecting the heat value is the carbon and hydrogen in the sample, and moisture contents in the sample reduce the heat value of the sample. According to the World Bank technical guidance report about municipal solid waste incineration, heat values of wastes should be higher than 1671 kcal/kg to be used as fuel sources. The increasing calorific value for MSW is mainly related to the increase of carbon content. This corresponds to many other studies [29,30]. However, the moisture content in waste biomass is also closely connected with calorific value [31]. It is also observed that the percentage of hydrogen (H) is associated with the highest moisture content in wood waste and obviously decreases the percentage of carbon in the sample (Table 1) and the calorific value. Hence, due to smaller moisture content in dried MSW, it had a greater energetic/calorific value comparing to wood waste as well. The properly performed drying process of biomass could lead to increase of its energetic value. Thereby, a substantial step in the processing and manufacture of MSW and wood biomass for energy yield production purposes is a drying process [31].

These results illustrate the opportunity to use MSW and wood biomass as a fuel to combustion or co-firing technologies. One should also note that calorific determination before the introduction of the materials in the boiler or reactor is useful to understand the energy performance of the combustion.

Fig. 3. Energetic (calorific) value in MSW and in wood biomass: a comparative result.

Table 2
XRF surface characteristics of MSW and wood.

№	Oxides	Samples	
		MSW, wt%	Wood, wt%
1	Na_2O	0,307	0,236
2	MgO	0,941	1,374
3	Al_2O_3	3,09	5,106
4	SiO_2	16,62	28,727
5	P_2O_5	5,075	1,897
6	SO_3	3,341	3,12
7	ClO	3,114	0,94
8	K_2O	6,447	7,29
9	CaO	50,344	36,561
10	TiO_2	1,66	1,369
11	Cr_2O_3	0	0,046
12	MnO	0,264	0,354
13	Fe_2O_3	8,223	12,063
14	NiO	0	0,03
15	CuO	0,057	0,07
16	ZnO	0,18	0,22
17	Rb_2O	0,024	0,042
18	SrO	0,196	0,291
19	ZrO	0	0,095
20	BaO	0,065	0,113
21	PbO	0,048	0,059

4. Conclusions and recommendations

This study presented the municipal solid and wood waste characterization of Urta-Chirchik District of the Republic of Uzbekistan.

- The proximate analysis of MSW and wood showed that the MSW contains less moisture content compared with wood waste which contributes to higher energetic (calorific) value of Urta-Chirchik municipal solid waste. As well as, a higher calorific value of MSW compared with wood can be also explained with the lower ash and fixed carbon contents.
- The ultimate analysis showed that MSW and wood biomass did not have significant differences in C composition. However, hydrogen (H) has a negative influence. This is due to the fact that hydrogen is associated with the water content. As it is known, the moisture content decreases the high heat value (HHV) of the biomass sources; therefore, hydrogen presents inverse proportionality with the heat obtained from combustion. The amount of sulfur and nitrogen in wood sample were smaller than in MSW, which means that during the thermochemical conversion of municipal solid and wood wastes, emissions containing sulphur and nitrogen will be significantly lower from the wood waste thermochemical mechanisms compared with MSW. However, emissions can be drastically reduced or eliminated by using highly selective and efficient metal catalysts supported by oxides, resistant to higher temperatures.

According to the thermochemical characterization of MSW and wood biomass species of Urta-Chirchik landfill, it can be concluded a promising usefulness and a good potential of waste to be used as renewable sources for bioenergy.

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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