TPH-2019 IOP Publishing

Journal of Physics: Conference Series **1359** (2019) 012065 doi:10.1088/1742-6596/1359/1/012065

Study of the physical-chemical characteristics of non-food solid waste combustion

K B Larionov, S A Tsibulskiy, K V Slyusarskiz, A A Tolokolnikov and V E Gubin

The Butakov Research Center, Tomsk Polytechnic University, 30 Lenin Avenue, Tomsk, 634050, Russia

Abstract. The ignition and combustion processes of six non-food municipal solid waste (MSW) samples of different type were studied. The samples of wood waste, rubber, leather, cardboard, textile and plastic were put into the combustion chamber at a temperature of 600 °C in air medium at atmospheric pressure. The observations were carried out by means of high-frequency video imaging of the combustion process. Based on the obtained results the characteristic times of the ignition delay, combustion of volatiles and carbon residue were defined. The highest values of ignition delay and combustion of the carbon residue times were obtained for rubber sample and were 11.3 and 285 s, respectively. Significant correlation was found between the time of volatiles and carbon residue combustion and the fixed carbon content of the sample: the higher the C^d content, the higher value of respective time. The concentration peaks of the gas-phase products release during combustion of non-food MSW were presented as well.

1. Introduction

The annual generation of municipal solid waste (MSW) in the world in 2019 is already more than 1.4 billion tons, with a predicted increase of up to 2.2 billion tons by 2025 and up to 9.5 billion tons by 2050 [1]. The utilization of MSW as an energy source can save fossil fuels, decrease consumption of water, electrical and thermal energy and reduce emissions of harmful substances into the atmosphere [2]. The simplest and most efficient way to convert solid waste into heat or electricity is its direct combustion in the furnaces of boilers of heating and power plants or district boiler houses. One of the significant problems of efficient incineration of MSW is its heterogeneous composition and unsatisfactory technical characteristics, such as low calorific value, high ash content and humidity. Many researchers are actively working to improve the technology of direct incineration of MSW, including selection of optimal performance characteristics of the thermochemical conversion process while taking into account the heterogeneity of the fuel composition. Analysis of numerous sources [3-4] indicates that existing research focuses on the application of multicomponent MSW compositions, the thermal transformation of which is being studied mainly by means of thermogravimetric and mass-spectrometric analysis. The oxidation conditions in the thermal analyzer chamber are significantly different from those in real energy equipment, primarily in terms of heat and mass transfer as well as heating rates. In current paper the results of experimental study of the conditions and characteristics of the ignition and subsequent combustion of six non-food MSW samples in a combustion chamber, the heating conditions in which are similar to real fuel-burning equipment.

2. Experimental section

2.1. Experimental section

The components of non-food MSW (wood waste, rubber, leather, cardboard, textile and plastic), which are widely used in household use, were taken as the samples studied. The grinding of raw materials was carried out mechanically using a cutting tool. The size of the fragments of the crushed material was less than 5 mm. After grinding, the technical characteristics (calorific value, content of analytical moisture, volatiles and ash) and the elemental composition (including content of C, H, N, S, O) of obtained samples were determined using standard methods [5] and the elemental composition analyzer Vario Micro Cube (Elementar, Germany), respectively. The obtained values of physical-chemical characteristics are presented in table 1. The following indices were used in table: ^{d} – dry fuel mass, ^{a} – analytical fuel mass, ^{daf} – dry ash-free fuel mass, ^{r} – working mass.

Table 1. Characteristics of non-food MSW.

MSW	**Elemental composition, mass. %**					**Technical characteristics**				
sample	C^d	H^d	N^d	S^d	O^d	A^d,%	W^a,%	V^{daf},%	Q_n^r, MJ/kg	ρ, g/cm^3
Wood waste	48,5	5,9	3,7	0	33,3	8,6	3,8	82,3	28,0	1,9
Rubber	65,4	6,4	0,9	1,7	3,9	21,7	0,4	39,0	18,4	4,2
Leather	50,5	6,3	10,5	1,2	25,1	6,4	4,9	81,1	21,9	1,3
Cardboard	40,6	5,0	0,2	0,0	32,7	21,5	3,1	74,9	14,3	1,9
Textile	45,4	6,3	0,2	0,0	38,6	9,5	2,6	94,0	17,7	1,6
Plastic	84,6	14,3	0,0	0,0	1,1	0,0	0,0	99,5	45,8	1,1

The characteristic differences in the chemical composition of the samples were noted. For rubber and leather samples the small sulfur content (less than 2%) was observed. At the same time, the hydrogen content for all samples (the only exception is plastic due to its technological origin) varied in range 5.0-6.5%. When analyzing the technical characteristics, it was noted that due to the absence of ash, the plastic sample had the highest calorific value Q_n^r and the yield of volatile substances V^{daf}. Despite high V^{daf} content (39.0-99.5%), the obtained Q_n^r values of all studied samples of non-food MSW are comparable with different types of energy fuel [1].

2.2 Granulation of studied samples

Granulation of fuel pellets was carried out by the method of cold pressing using the hydraulic manual press [6]. The only exception was rubber sample because this material has high elasticity. Samples (weighing ~ 0.20 ± 0.01 g) of ground MSW were placed in a matrix with an 8 mm cylindrical hole and a stop cup which was fixed to the base. The pressing was carried out with a punch of the similar diameter, fixed on the hydraulic mechanism of the press. Thepressing force was 2 tons (in metric units). The density of the obtained fuel pellets are presented in table 1.

2.3.Study of ignition and combustion processes

The study of ignition and subsequent combustion of non-food MSW was carried out using an experimental setup, the concept of which is presented in figure 1.

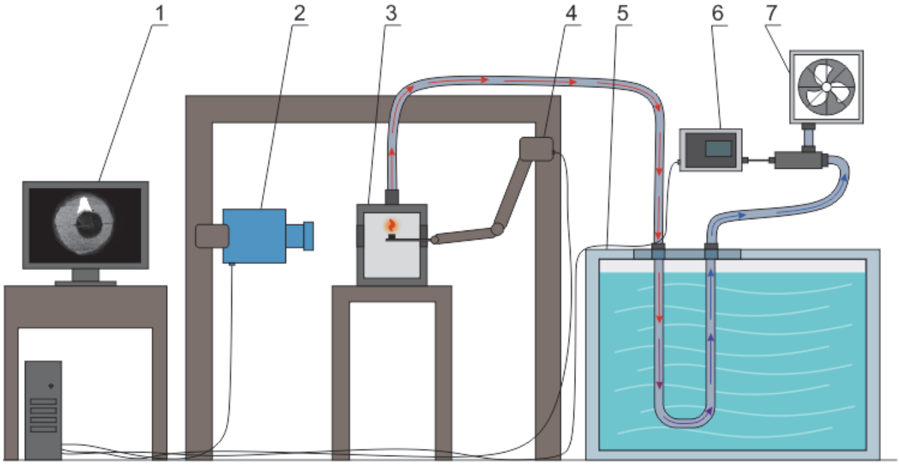


Figure 1. Experimental setup for the study of ignition and subsequent combustion of non-food MSW granules (1 – automated workplace (AWP), 2 – high-frequency video camera, 3 – combustion chamber with controlled temperature, 4 – platform of the coordinate mechanism for feeding MSW granules into the combustion chamber, 5 – cooler of outlet MSW gas-phase combustion products, 6 – in-line analyzer of MSW gas-phase combustion products, 7 – ventilation system).

The main elements of the setup (figure 1) are as follows: temperature controlled TSMP Ltd R14-U furnace with a digital temperature controller (measurement error below 1 °C) and a 0.012 m^3volume; FASTCAM CA4 5 high-frequency video camera (Photron, USA) with 1024 × 1024image format, 105 frames per second frequency; platform with the coordinate mechanism intended for the input of fuel pellets into the furnace with an error of movement in space below 1 mm; in-line analyzer of gas-phase combustion products Binar - 1P (ARTGAZ, Russia). The method of studying the processes of ignition and combustion of MSW fuel pellets consisted of several stages. In a temperature-controlled furnace (3) the required heating temperature was set (600 °C). The deviations of the air temperature in the combustion chamber from the average value for the volume did not exceed 1 - 3 °C. The fuel pellet was placed on the holder of the coordinate mechanism (4), the course of which was calibrated according to a given coordinate of the combustion chamber center and was activated using the AWP (1). Simultaneously with the beginning of the movement of the rod with the granule, video fixation (2) was performed in the direction of the combustion chamber. Next, the produced gas-phase combustion products went along the path through the cooling device (5) and in-line gas analyzer (6) to the ventilation system (7). The experiment was carried out at atmospheric pressure. A comparative assessment of the characteristics of ignition and combustion was carried out using the times of ignition delay, flame combustion and carbon residue combustion. The ignition delay time was measured from the moment when the holder with the fuel granule entered the furnace chamber until the formation of a visible glow of the surface of the fuel granule, corresponding to the ignition. The periods of volatiles and residual carbon combustion were recorded from the moment of formation of visible luminescence and ending with the disappearance of the flame and the attenuation of the resulting carbon residue of the granule subjected to thermal decomposition, respectively. To improve the accuracy of the results obtained, at least 5 experiments were conducted for each sample under similar conditions. The quantitative registration of gas-phase compounds (CO_2, CO, SO_2, NO, H_2S) released during the combustion of non-food MSW was carried out as well.

3. Results and discussion

Figure 2 shows the time of ignition delay, combustion of volatiles (accompanied by the formation of a flame) and carbon residue calculated using high-frequency video. The highest values of the ignition delay time τ_i of non-food MSW (figure 2a) were observed for textile and rubber samples (12.8 and 11.3 s, respectively). For other samples, the value of this parameter varies in range 7.8–8.9 s.

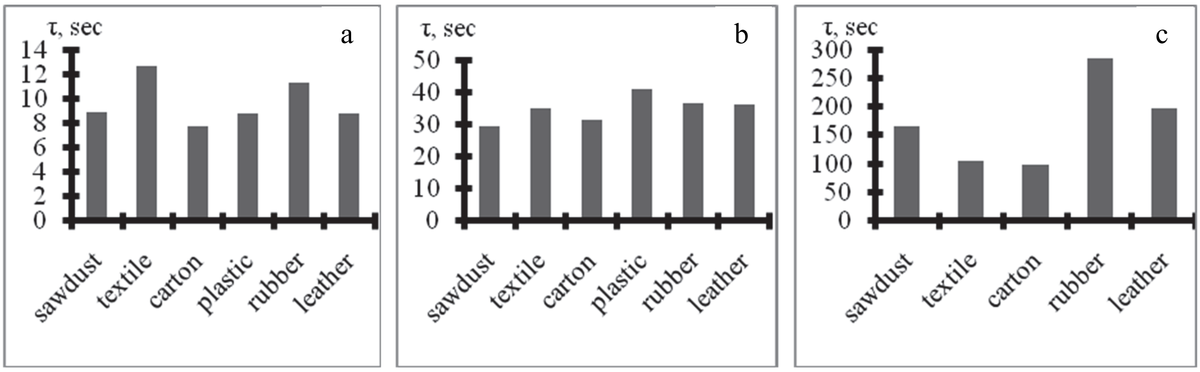
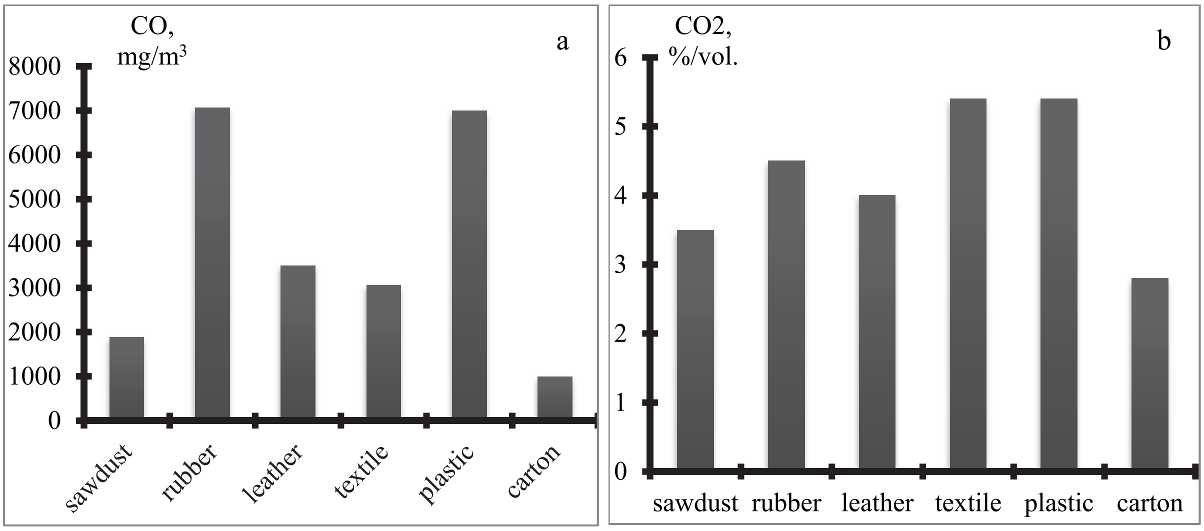


Figure 2.Time of ignition delay(a), combustion of volatiles (b) and carbon residue (c) at 600 °C.

The longest flame combustion time (figure 2b) was observed for the plastic ($\tau_f = 41$ s), which could be explained by the physical-chemical structure of the sample (table 1), namely, by high volatiles content in the sample. It should be noted that there is no direct correlation between the flame combustion time and the volatile content. It may be explained by different nature of volatile components in each sample. The correlation between the flame combustion time and the carbon content of the sample (with the exception of secondary sawdust) was also found: the higher C^d content resulted in the increase of the flame combustion time of volatiles. It is worth mentioning that, unlike other samples, the stage of flame combustion in the burning process of plastic is final. In turn, the longest combustion time of the carbon residue (figure 2c) is observed for the rubber sample ($\tau_b = 285$ s). By decreasing the time of combustion of carbon residue the following row of samples may be formed: rubber, leather, sawdust, textile and cardboard. Similar to the flame combustion time, the qualitative dependence of the burning time of the carbon residue on the C^d content was registered (table 1).

The concentration maximums of the gas-phase combustion products release are presented in figure 3.



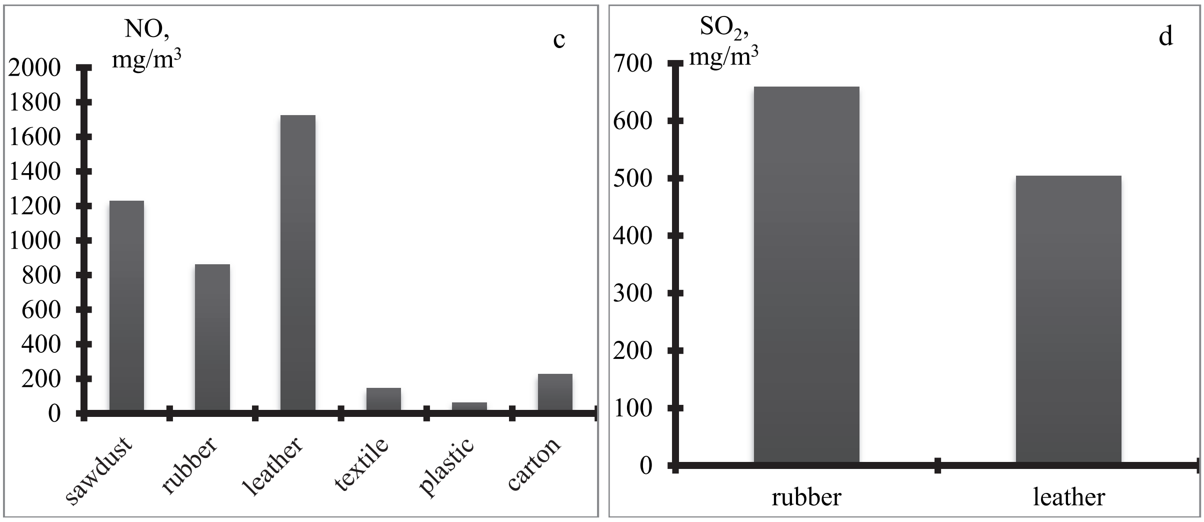


Figure 3. Concentration maximums of the gas-phase combustion products release during combustion of non-food MSW.

The highest concentration maximums of carbon monoxide release (the main oxidation product of a combustible substance) were recorded for plastic and rubber samples, which was about 7000 mg/m^3. In turn, for a textile sample with a relatively low CO emission value, one of the largest concentration extremums of carbon dioxide release was traced along with rubber and plastic samples (about 5.5 vol.%). Due to the presence of sulfur in rubber and leather samples (table 1) the release of SO_2 was observed; its concentration maximums were 510 and 690 mg/m^3, respectively. The correlation between NO emissions and nitrogen content was observed for all studied samples: the higher N^d resulted in a higher value of the nitric oxide concentration maximum. For a plastic sample, the appearance of NO can be attributed to the involvement of molecular nitrogen from the oxidizing medium (air) during flame combustion.

Conclusion

The physical-chemical characteristics of ignition and subsequent combustion processes of non-food MSW in the combustion chamber, where the heating conditions similar to real fuel-burning equipment were defined. It was found that the maximum ignition delay times were observed for textile and rubber samples, the maximum flame combustion times – for plastic and rubber, the carbon residue combustion times – for rubber and sawdust. A qualitative correlation between the value of carbon content and the time of volatiles (in the flame mode) and the carbon residue combustion was observed. According to the analysis of the gas-phase combustion products release, the maximum concentrations of the formed compounds have been determined. A direct correlation was observed between the release of NO and the nitrogen content in the elemental composition of non-food MSW.

Acknowledgments

The work was performed with financial support of the Ministry of Education and Science of the Russian Federation within the project №13.7644.2017/8.9

Reference

[1] Fu Z, Zhu J, Barghi S, Zhao Y, Luo Z, Duan C 2019 *Fuel* **243** 509
[2] Ribeiro A, Soares M, Castro C, Vilarinho C, Carvalho J 2019 *Lect. Notes. Electr. Engin.* **236** 715
[3] Muthuraman M, Namioka T, Yoshikawa K 2010 *Fuel Process. Technol.* **91** 550
[4] Liu G, Liao Y, Guo S, Ma X, Zeng C, Wu J 2016 *Appl. Therm. Eng.* **98** 400
[5] Tabakaev R, Kanipa I, Astafev A, Dubinin Y, Yazykov N, Zavorin A, Yakovlev V 2019 *Fuel* **245** 29
[6] Kuznetsov G,Yankovskii S 2019 *Therm. Eng.* **66** 133