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UDC 33.013.6

Experimentally determined MSW sample incineration heat and revealing its auto-combustion capability

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Abstract
The current research experimentally simulates the combustion processes for municipal solid wastes of a given composition with a boiler-utilizer pursing the objective to study the opportunities for autocombustion and to determine the heat of incineration. The research is carried with the samples made from municipal solid wastes (hereinafter referred as MSW) simulating their average morphology in the city of Kyiv, Ukraine. Their incineration was performed in the laboratory boiler-utilizer and the incineration heat of 1 kg of solid waste has been defined. The values of incineration heat, as established by the experiments, correspond to the predicted values. However, it was not possible to keep the required temperature of 850 °C in the experimental equipment and to reach auto-combustion even with that MSW composition, with which auto-combustion is possible in accordance to the Tanner diagram. In the article, we substantiate that the MSW combustion process for the industrial furnaces cannot be studied with an experimental boiler-utilizer; for this purpose it is expedient to use the appropriate calculation models based on the thermal balance sheet of the furnace. For the practical use, the research has showed that the industrial plants and sites, which practice MSW incineration, can quite accurately determine the heat of MSW incineration by direct combustion of the appropriate samples.
Keywords: MUNICIPAL SOLID WASTES, TANNER DIAGRAM, HEAT OF INCINERATION, MODEL SAMPLE, BOILER-UTILIZER, PREDICTED VALUE.

The problem and its connection with scientific and practical issues. The heat of MSW incineration is one of the most important parameters that determine the technological features of combustion process [1]. In the case of insufficient combustion heat, the self-burning of MSW or MSW auto-combustion becomes impossible and the necessity to burn the additional high calorific fuel arises. Natural gas is commonly used for this purpose.

The analysis of the publications on the research topic. The feasibility of self-combustion is determined by the contents of the combustible substances and ballasting components (moisture and ash) in the MSW.

The existing results of the numerous studies, carried out on combustion of various types of solid fuels and MSW and expressed in the form of the Tanner Diagram, evidence that MSW combustion without additional caloric fuel is possible under the following aggregate conditions:

$$W < 50\%,\ A < 60\%,\ C > 25\%,$$

where W is humidity,

A - ash content,

C - the combustible mass.

Figure 1 shows the Tanner Diagram [2, 3], where ABCDE stands for the burning area without additional fuel.

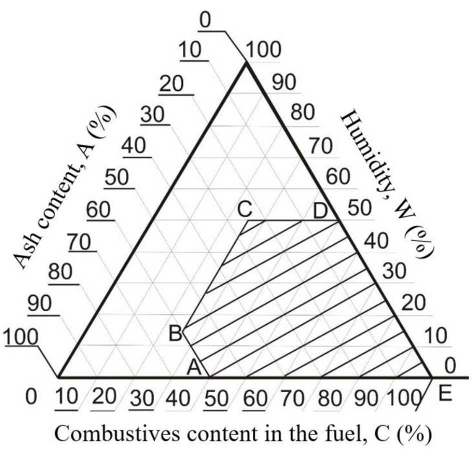

Fig.1. The Tanner Diagram for MSW combustibility evaluation

In practice, the Tanner diagram is used to pre-evaluate the combustibility of composite mixtures. However, there is no confidence, in fact, that in all the cases where auto-combustion is probable according to the Tanner diagram, it is possible to carry out MSW incineration in the dedicated equipment.

The research problem statement. The purpose of this work is to study experimentally the processes of MSW combustion of a given composition within an experimental waste boiler-utilizer, which simulates the burning of MSW in a dense layer on mechanized grates, to find a solution for the question of the auto-combustion feasibility and to determine MSW incineration heat.

Research materials and methods. The experimental studies of MSW model sample combustion were conducted on a laboratory experimental plant with KS-TGV-12.5 boiler-utilizer. They were carried out in accordance with the methodologies for defining the morphological composition, for determining the incineration heat with respect to the sample of the specified morphological composition and ash content. MSW for sampling is taken from plant "Energy" supplies [4].

Publication [4] provided our research with a list of measurements, selected a set of the instruments, gave a list of components for preparation and described all the necessary steps of the MSW model sample production as well as provided a set of calculated dependencies, which allow defining a desired MSD incineration heat value by using the data actually obtained from the instruments as an argument.

Thus, the final expression for MSW incineration heat is read as:

$$Q^{MSW} = \frac{Q_{generated} - Q_{gas}}{P} \qquad (1)$$

where $Q_{generated}$ – the amount of heat generated during the experiment (kJ);

Q_{gas} – the quantity of heat generated by additional gas combustion (kJ)

P – weight of a model sample with the gain of the applied moisture (kg).

The value of $Q_{generated}$ is determined from the calculation of the heat balance sheet analysis for the boiler-utilizer, which is made according to the data of the instruments:

$$Q_{generated} = (Q_1 + Q_2 + Q^{steam} + Q_3 + Q_5 + Q_6)\cdot\frac{100}{100\text{-}q_4} \qquad (2),$$

where:

Q_1 – the amount of heat perceived by the cooling circuit in the experiment kJ);

Q_2 – loss of heat with flue gases leaving the boiler-utilizer (kJ);

Q^{steam} – heat loss for evaporation of MSW sample moisture (kJ);

Q_3 – heat loss with incomplete combustion (kJ);

q_4 – relative combustible losses (%);

Q_5 – loss of heat from cooling the surface of the boiler-utilizer (kJ);

Q_6 – heat losses with sensible heat of slag (kJ).

The models samples were produced on the basis of the industrial plant Energy statistics concerning the MSW morphology; the contents of the main components correspond to the average MSW composition. Table 1 shows an example of this composition in the summer months of 2016, with an average humidity of 57.4%.

Additionally, for the further study of the moisture content, we considered also the combustion of model samples with the same content of the main components in the combustible mass but with an average humidity of 28.6% corresponding to the air-dry state.

Table 1. The morphological composition of MSW model samples used for the research

№	MSW component	Component composition, %
1	Food waste	31.12
2	Paper and cardboard	13.76
3	Polymers (plastics)	14.95
4	Glass and ceramics	18.34
5	Metals	1.4
6	Soft goods (textiles)	4.71
7	Wood	3.08
8	Rubber and leather	2.25
9	The residue of solid household waste after the removal of the components	10.42
10	In total	100
	Average humidity (%)	57.4

Within the frame of this work, the following experimental studies were conducted:

Mode 1: The incineration of MSW model sample with a given morphological composition and humidity, with the addition of high caloric gas for support.

Mode 2: The incineration of a MSW model sample of a specified morphological composition in air-dry state, with gas support.

Mode 3: The incineration of a MSW model sample of a specified morphological composition in an air-dry state, without gas support.

For all the experiments, the following sequence was observed: heating the boiler-utilizer by burning the propane-butane mixture until stabilizing the temperature of the water at the outlet from the cooling circuit and the MSW charging. In the first and the second incineration modes, the natural gas support was applied, its feeding was terminated after incineration of MSW model samples in both cases evidenced by visual inspection, while with the third mode the gas was shut off after MSW heating up. After the incineration process was completed, the residue was weighed and combusted again in a muffle furnace. Afterwards obtained ash residue was finally weighed.

Results and discussion. Let us consider the parameters of the incineration processes for the thereof modes. They can be analyzed by as follows: the dynamics of the temperature change in the boiler-utilizer, the temperatures of the flue gases during the incineration and MSW model sample humidity.

In the experiment of the first mode (refer to figure 2), the temperature within the boiler-utilizer during propane-butane combustion was within 220…270 °C. The charge of the wet MSW sample of 4 kg in weight and the addition of 1 liter of water under the fire-grate with the purpose to raise the humidity led to the drop in the temperature down to 120 °C. Therefore, the MSW sample was moisture-conditioned as W=57.4 %. After 15 min of intensive MSW mixing and heating, the combustion process began.

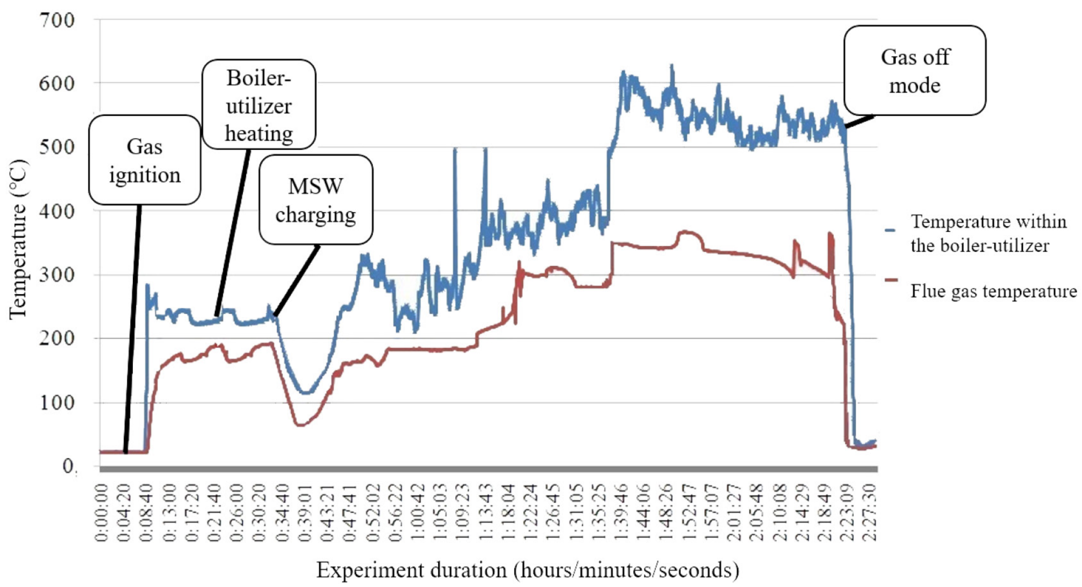

Fig. 2. MSW incineration with gas for support. Moisture level of W=57.4 %

The furnace temperature was 400...600 °C.. Based on the obtained results, the calculation was carried out to determine the heat amount, which was released at burning. By displacing the MSW sample, we managed to incinerate it in the experimental boiler-utilizer, but due to the heat loss on evaporation of the moisture in the sample, the heat intensity rate was released as much as 1062...1195 kcal /kg during the MSW incineration and the ash in the sample was 29.6 %.

The incineration of the sample with such moisture content requires the support of a large amount of an additional energy carrier even when sample bed thorough mixing.

Moreover, the similar dynamics of the temperature change within the boiler-utilizer and flue-gas temperature was observed at incineration of MSW sample of a certain morphological composition under air-dry condition with the humidity of 28.6 %, as shown in figure 3. The supporting gas feed and the displacement of the sample bed were carried on at all the time in the entire course of the active experimental stage. The temperature in the boiler-utilizer during MSW combustion was within the range of 400...650 °C. The amount of heat, released at combustion of MSW sample in the course of the experiments, was 1547...1662 kcal /kg of MSW and the ash content was 25.3 %.

Furthermore, we made an attempt to incinerate the MSW sample of the certain morphological composition in air-dry condition without applying gas support. The dynamics of the temperature change is given in figure 4.

The temperature in the boiler-utilizer after ignition of MSW was within 680...720 °C. After MSW heating

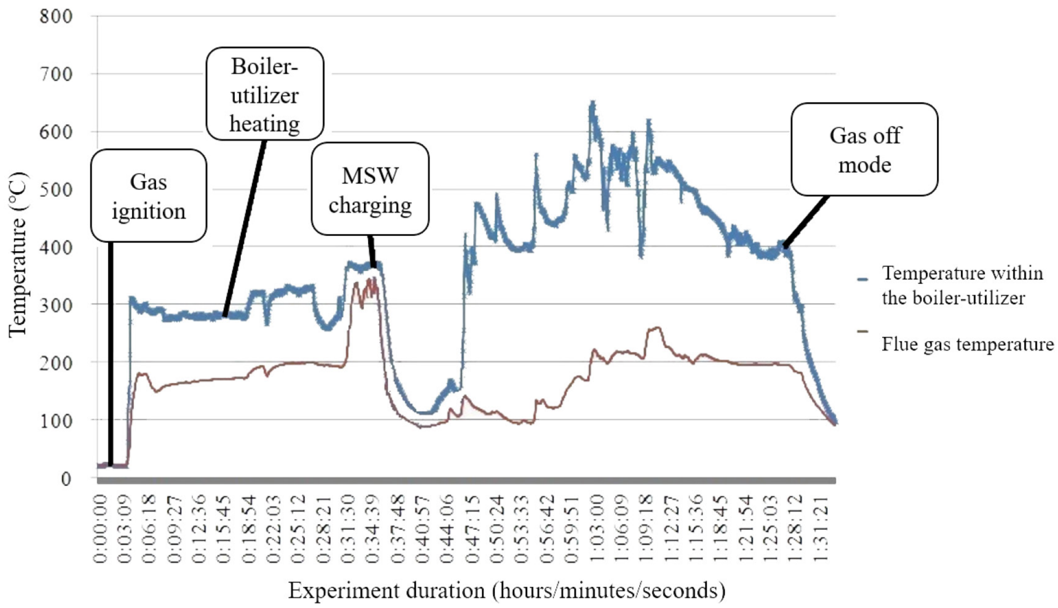

Fig. 3. MSW incineration with gas for support under air-dry condition. Moisture level of W= 28.6 %

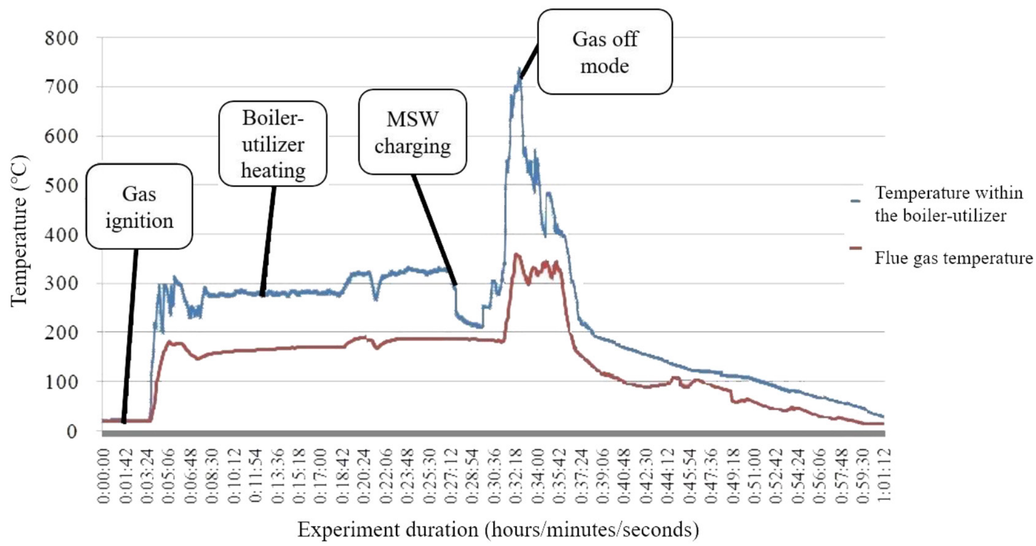

Fig. 4. MSW incineration under air-dry condition without gas support

up, gas feeding was shut off. In about 3 minutes, MSW combustion started to decrease, the process of active combustion ceased and the MSW smoking followed. After MSW residue was cooled down, it was weighed and showed 4.6 kg.

The summarized characteristics of air-dry MSW sample with moisture of 28.6 % is completely within the zone of autocombustion, which indicates the theoretical feasibility of MSW autocombustion of the stated morphological composition. From the practical standpoint, the feasibility of autocombustion depends on the technique applied and the appropriate specific capacities of the equipment, namely sufficient thermal inertia of an industrial boiler-utilizer, the high capacities of which a laboratory test plant cannot have. For this reason, the incineration of air-dry MSW sample in the experimental boiler-utilizer can take place also in the mode of additional support by propane and butane mixture.

In order to compare obtained results against the reference data [3, 5], the calculations of predicted calorific capacitance of MSW have been conducted for the time period of 2016 summer months in accordance with calorific efficiency of MSW.

Calculation results of calorific efficiency for MSW of summer months. Average calorific efficiency values of certain components of Ukrainian MSW are known from reference literature [3, 5], given in table 2.

The predicted value of incineration heat for all the MSW mass has been calculated in accordance with incineration heat data of certain MSW components typical for Ukraine and described in the earlier publications.

The results of the studies on the combusted MSW model sample with the morphology averaged for 3 summer months of 2016 can be summarized in the form of the table (refer to Table 4) and compared against the calculated predicted low value of MSW calorific efficiency, in accordance with the reference data of low incineration heat of Ukrainian MSW components.

Therefore, from the analysis of the results given in the table, it is obvious that experimentally determined value of calorific efficiency of MSW with moisture of 57.4 % corresponds to the calculated data with high accuracy while for the sample with moisture of 28.6 %, the difference between the experimentally proven and predicted values of incineration heat is 15%.

For all the experiments including the ones, which have been conducted with MSW morphology material of the other seasons of the year, it is necessary to note some specific features apart from the impossibility to simulate autocombustion. First and foremost, it is the impossibility to reaching the temperature of 850 °C in the boiler-utilizer, which is necessary with respect to the environmental indicators (complete destructive combustion of dioxins and others). Secondly, the constant instability of the temperature, manifested as much as ±100 °C within the volume of the experimental boiler-utilizer, is also the prohibitive for the industrial use of waste incineration plants.

All the above has brought the idea that for studying MSW combustion process of in industrial boiler-utilizers, it is permissible to use appropriate calculation models based on heat balance sheet for this equipment and to take into account the temperature level in combustion furnace of the boiler-utilizer. The developments of such a kind are described in the principle parts of our earlier publication [7]: material and energy balance sheet of MSW combustion, energy balance sheet of natural gas combustion, material and energy balance sheet of MSW and natural gas combined combustion, general material heat balance of the process. This allows carrying out the studies for both independent MSW combustion and MSW combustion together with the natural gas. With the help of this development we can solve problems of autocombustion feasibility of specific MSW under conditions of industrial equipment, which is able to reach the temperature level of 850 °C.

Table 4. The summarized results of MSW sample combustion studies and calculated predicted low value of MSW calorific efficiency

Mod No	Given parameters	Incineration mode		Obtained results		Predicted low value of MSW calorific efficiency of in (summer months)	
	Moisture of MSW sample (%)	Availability of gas support	Displacement of sample bed	Amount of heat released at MSW sample incineration (kcal /kg)	Sample ash (%)	min	max
	W	*yes/no*	*yes/no*	Q_{Σ}	*A*		
1	0					2482	2829
2	28.6	yes	yes	1547...1662	25.3	1772	2020
3	57.4	yes	yes	1062...1195	29.6	1057	1205

Conclusions and directions for the future research. If the combustion of MSW sample with a certain morphological composition without introduction of additional moisture (air-dry condition with 28.6 % of moisture) is accompanied by the support of high calorific gas combustion and the sample bed displacing takes place, the MSW sample itself releases the heat of 1547...1662 kcal /kg (the contribution of natural gas support is not taken into account). In accordance with Tanner diagram, the composition of the considered sample is within autocombustion zone (although located virtually on its boundary), which speaks for theoretical possibility for MSW autocombustion of such a morphological composition. However, under conditions of the experimental boiler-utilizer, we failed to reach autocombustion of MSW sample with the stated composition. This prompts that the autocombustion feasibility depends on the combustion technique, specific technical capabilities of the appropriate equipment, in particular, sufficient heat inertia of the boiler, etc.

Such a result says that for the research of MSW combustion process in industrial boiler-utilizers it is permissible to use the appropriate calculation models based on energy balance of the boiler-utilizer.

In combustion of MSW sample of the same composition but with moisture of 57.4 % (introduction of additional moisture has taken place) together with high calorific gas support and with displacement of MSW sample, the sample itself gives 1062...1195 kcal / kg to release without contribution of natural gas support. In accordance with the Tanner diagram, the compared description of such MSW is out of the autocombustion zone, which evidences the necessity to apply the additional fuel. The incineration for such a wet sample requires a big amount of the additional energy carrier for support even at thorough mixing or displacing the sample bed.

In order to reduce the additional fuel consumption at MSW incineration and to enhance the energy potential efficiency of MSW, it is necessary to carry out MSW incineration process with lesser content of moisture.

The most efficient way to reduce the moisture content of MSW is optimization in the arrangement at the stage of wastes collecting. In accordance with European practice, MSW is collected into closed reservoirs located under shelters to avoid impingement of water into MSW.

As the replacement of the existing MSW reservoirs for the closed ones requires significant financial expenses and time, it is reasonable to arrange a process of moisture decrease by using drainage in the hoppers, and drying of MSW before feeding into the industrial boiler-utilizer, with using, in particular, heat of flue gases.

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